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TITLE: OPTICAL DEVICE, OPTICAL SYSTEM, METHOD OF PRODUCTION OF SAME, AND MOLD FOR PRODUCTION OF SAME
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SIR;

CERTIFIED TRANSLATION

I, Takahisa SATOH, am an official translator of the Japanese language into the English language and I hereby certify that the attached comprises an accurate translation into English of Japanese Application No. 2000-132897, filed on April 27, 2000.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

December 3, 2003 — Takahisa Satoh

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[TITLE OF THE INVENTION] Optical Device, Method for Production of Optical Device, and Optical System

[CLAIMS]

[Claim 1]

An optical device comprising:

a base material made of a first optical material and

a second optical material having a different refractive index from that of the first optical material, wherein

the base material has a concavity and wherein the second optical material is filled in this concavity.

[Claim 2]

An optical device as set forth in claim 1, wherein

the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and

the base material has a second flat face located at an area around a circumferential edge of the concavity and a first flat face parallel or approximately parallel to the second flat face.

[Claim 3]

An optical device as set forth in claim 2, wherein the surface of the second optical material filled in the concavity and the second flat face are parallel or approximately parallel.

[Claim 4]

An optical device as set forth in claim 3, wherein the surface of the second optical material filled in the concavity and the second flat face are located in an identical plane or approximately an identical plane.

[Claim 5]

An optical device as set forth in claim 1, wherein

the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and

the shape of the surface of the concavity when the concavity is cut along its symmetry axis is an arc or approximately an arc.

[Claim 6]

An optical device as set forth in claim 1, wherein the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 7]

An optical device as set forth in claim 1, wherein

the second optical material is a liquid-like optical material and

th surface of the base material forming the concavity is formed with a layer made of an optical mat rial for sealing the concavity filled with the second

optical material.

[Claim 8]

An optical device as set forth in claim 7, wherein

the layer for sealing the concavity is made a film having a constant or approximately constant thickness, and

the second optical material is an optical oil or a liquid crystal.

[Claim 9]

An optical system comprising first and second optical devices, wherein

the first optical device has

a first base material made of a first optical material and

a second optical material having a different refractive index from the first optical material,

the first base material has a first concavity having a rotationally symmetric or approximately rotationally symmetric shape,

the second optical material is filled in this first concavity,

the second optical device has

a second base material made of a third optical material and

a fourth optical material having a different

refractiv index from the third optical material,

the second base material has a second concavity having a rotationally symmetric or approximately rotationally symmetric shape,

the fourth optical material is filled in this second concavity, and

the first and second optical devices are bonded so that symmetry axes of the first and second concavities are located on an identical straight line or approximately identical straight line.

[Claim 10]

An optical system as set forth in claim 9, wherein

the first base material has a second flat face located at the area around the circumferential edge of the concavity and a first flat face parallel or approximately parallel with respect to the second flat face,

the surface of the second optical material filled in the first concavity and the second flat face are located in an identical plane or approximately identical plane,

the second base material has a fourth flat face located at the area around the circumferential edge of the second concavity and a third flat face parallel or approximately parallel with r spect to the fourth flat face, and

one of the first and second flat faces is bonded with the third flat face.

[Claim 11]

An optical system as set forth in claim 10, wherein the surface of the fourth optical material filled in the second concavity and the fourth flat face are parallel or approximately parallel.

[Claim 12]

An optical system as set forth in claim 11, wherein the surface of the fourth optical material filled in the second concavity and the fourth flat face are located in an identical plane or approximately identical plane.

[Claim 13]

An optical system as set forth in claim 10, wherein

the first concavity is larger than the second concavity,

the second flat face of the first base material and the third flat face of the second base material are bonded,

the second optical material has a larger refractive index than the first optical material,

the fourth optical material has a larger refractive index than the third optical material, and

a solid immersion lens is comprised by the second optical material filled in the first concavity and the

fourth optical material filled in the second concavity.

[Claim 14]

An optical system as set forth in claim 9, comprising a slider of an optical head attached to a swing arm.

[Claim 15]

An optical system as set forth in claim 14, wherein, the third optical material is aluminum oxide.

[Claim 16]

An optical system comprising an optical device and a lens, wherein

the optical device has

a base material made of a first optical material and

a second optical material having a different refractive index from the first optical material,

the base material has a concavity having a rotationally symmetric or approximately rotationally symmetric shape,

the second optical material is filled in this concavity,

the lens is shaped by a rotationally symmetric or approximately rotationally symmetric curved face and the flat fac , and

the lens and the optical device are bonded so that the symmetry axis of the concavity and an optical axis of

the lens are located on an identical straight line or approximately identical straight line.

[Claim 17]

An optical system as set forth in claim 16, wherein

the base material has a second flat face located at the area around the circumferential edge of the concavity and a first flat face parallel or approximately parallel with respect to the second flat face, and

the flat face of the lens and the first flat face of the optical device are bonded.

[Claim 18]

An optical system as set forth in claim 17, wherein the surface of the second optical material filled in the concavity and the second flat face are parallel or approximately parallel.

[Claim 19]

An optical system as set forth in claim 18, wherein the surface of the second optical material filled in the concavity and the second flat face are located in an identical plane or approximately identical plane.

[Claim 20]

An optical system as set forth in claim 17, wherein

the l ns has a convex shape and is larger than the concavity,

the second optical material has a larger refractive

index than the first optical material, and

the second optical material filled in the concavity and the lens comprise a solid immersion lens.

[Claim 21]

An optical system as set forth in claim 16, comprising a slider of an optical head attached to a swing arm.

[Claim 22]

An optical system as set forth in claim 21, wherein the first optical material is aluminum oxide.

[Claim 23]

A method of production of an optical device comprised of a concavity of a base material made of a first optical material filled with second optical material having a different refractive index from the first optical material, comprising

a step of using a metallic mold formed with a projection projecting out into a cavity to mold the base material made of the first optical material with a concavity reproducing the shape of the projection and

a step of filling the second optical material in the concavity of the molded base material.

[Claim 24]

A method of production of an optical d vice as set forth in claim 23, further comprising a step of

flattening th surfac of th second optical material filled in the concavity.

[Claim 25]

A method of production of an optical device as set forth in claim 25, wherein

the projection of the base material has a rotationally symmetric or approximately rotationally symmetric shape, and

in the flattening step, the surface of the second optical material is polished so that a flat plane vertical or approximately vertical with respect to the symmetry axis of the concavity reproducing the shape of the projection is formed.

[Claim 26]

A method of production of an optical device as set forth in claim 24, further comprising a step of polishing the base material so that a flat face parallel or approximately parallel to the surface of the flattened second optical material is formed.

[Claim 27]

A method of production of an optical device as set forth in claim 23, wherein

the projection has a rotationally symmetric or approximat ly rotationally symmetric shape, and

the shap of the surfac of the projection when the

projection is cut along its symmetry axis is an arc or approximately an arc.

[Claim 28]

A method of production of an optical device as set forth in claim 23, the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 29]

A method of production of an optical device as set forth in claim 23, wherein

the second optical material is a liquid-like optical material, and

the step of filling the second optical material has

a step of filling the second optical material in the concavity of the molded base material and

a step of sealing the concavity filled with the second optical material by a layer made of the optical material.

[Claim 30]

A method of production of an optical device as set forth in claim 29, wher in

the layer sealing the concavity is formed by a film having a constant or approximately constant thickness,

and

the second optical material is an optical oil or liquid crystal.

[Claim 31]

A method of production of an optical device comprised of a concavity of a base material made of a first optical material filled with a second optical material having a different refractive index from the first optical material, comprising

a step of forming a resist having a hole in the flat face of the base material made of the first optical material,

a step of forming a concavity corresponding to the hole in the base material by etching,

a step of removing a resist from the base material with the concavity formed therein, and

a step of filling the second optical material in the concavity of the base material from which the resist is removed.

[Claim 32]

A method of production of an optical device as set forth in claim 31, further comprising a step of flattening the surface of the second optical material filled in the concavity.

[Claim 33]

A m thod of production of an optical device as set forth in claim 32, wherein

the hole is circular or approximately circular,

the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and

in the flattening step, the surface of the second optical material is polished so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity is formed.

[Claim 34]

A method of production of an optical device as set forth in claim 32, further comprising a step of polishing the base material so that a flat face parallel or approximately parallel with respect to the surface of the flattened second optical material is formed.

[Claim 35]

A method of production of an optical device as set forth in claim 31, wherein

the hole is circular or approximately circular,

the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and

the shape of the surface of the concavity in the case when the concavity is cut along its symmetry axis is an arc or approximat ly an arc.

[Claim 36]

A m thod of production of an optical device as set forth in claim 31, wherein the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 37]

A method of production of an optical device as set forth in claim 31, wherein

the second optical material is a liquid-like optical material, and

the step of filling the second optical material has

a step of filling the second optical material in the concavity of the base material from which the resist is removed and

a step of sealing the concavity filled with the second optical material by a layer made of an optical material.

[Claim 38]

A method of production of an optical device as set forth in claim 37, wherein

the layer for sealing the concavity is formed by a film having a constant or approximately constant thickness, and

th second optical material is an optical oil or

liquid crystal.

[Claim 39]

A method for manufacturing an optical device comprised of a concavity of a base material made of a first optical material filled with a second optical material having a different refractive index from the first optical material, comprising

a step of forming on a second base material provided with a projection and having a flat area around the projection the first base material made of a layer of the first optical material burying the projection,

a step of flattening the surface of the first base material to form a flat face and bonding the related flat face to a third base material made of a third optical material,

a step of removing the second base material from the first base material bonded to the third base material to expose the concavity reproducing the shape of the projection in the first base material, and

a step of filling the second optical material in the concavity of the exposed first base material.

[Claim 40]

A method of production of an optical devic as set forth in claim 39, furth r comprising a step of flatt ning the surface of the second optical material

filled in the concavity.

[Claim 41]

A method of production of an optical device as set forth in claim 40, wherein

the projection has a rotationally symmetric or approximately rotationally symmetric shape, and

in the flattening step, the surface of the second optical material is polished so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity reproducing the shape of the projection is formed.

[Claim 42]

A method of production of an optical device as set forth in claim 40, further comprising a step of polishing the third base material so that a flat face parallel or approximately parallel to the surface of the flattened second optical material is formed.

[Claim 43]

A method of production of an optical device as set forth in claim 39, wherein

the projection has a rotationally symmetric or approximately rotationally symmetric shape, and

the shape of the surface of the proj ction wh n the projection is cut along its symmetry axis is an arc or approximat ly an arc.

[Claim 44]

A method of production of an optical device as set forth in claim 39, wherein the first optical material and the third optical material are identical optical materials.

[Claim 45]

A method of production of an optical device as set forth in claim 39, wherein the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 46]

A method of production of an optical device as set forth in claim 39, wherein

the second optical material is a liquid-like optical material, and

the step of filling the second optical material has

a step of filling the second optical material in the concavity of the exposed first base material and

a step of sealing the concavity filled with the second optical material by a layer made of an optical material.

[Claim 47]

A method of production of an optical device as set

forth in claim 46, wherein

the layer for sealing the concavity is formed by a film having a constant or approximately constant thickness, and

the second optical material is an optical oil or liquid crystal.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field of the Invention]

The present invention relates to an optical device and a method for production of the same and to an optical system having the optical device.

[0002]

[Prior Art]

When producing a lens, the following first to third methods of production have been known.

The first method of production is a method of filling an optical material in a metallic mold machined to an intended lens shape and producing the lens by simple molding.

The second method of production is a method of utilizing reactive ion etching (RIE) or other etching and using a photo resist or the like as a mask (etching mask) to etch an optical material to a predetermined shap to thereby produce a lens made of the related optical

material.

The third method of production is a method of mechanically polishing a base material made of an optical material to the lens shape to produce the lens.

[0003]

[Problems to be Solved by the Invention]

In the conventional first method of production, that is, the method using simple molding, it is difficult to produce a small sized lens having a large numerical aperture, so it is difficult to reduce the lens diameter to 1 mm or less.

In the conventional second method of production, that is, the method using RIE or other etching, the optical material is limited, so it is difficult to use a material having a high refractive index and it is difficult to realize a lens having a large numerical aperture NA.

In the conventional third method of production, it is difficult to manufacture a small sized lens.

[0004]

If increasing the numerical aperture of the lens, it is possible to make the size of a light spot created after passing through th lens small. It is desirable from the viewpoint of increase of the capacity of an optical disc to enlarge the numerical ap rtur NA of the

lens (object l ns) of an optical head.

Also, lenses and other optical devices are being used for various optical apparatuses. Reduction of the size of the optical devices is desirable from the viewpoint of the reduction of size of the optical apparatuses.

[0005]

In order to realize an optical device having a large numerical aperture, a large refractive index of the optical material is effective.

As an optical material having a high refractive index in a region of visible light, there are titanium oxide, tantalum oxide, gallium phosphate (gallium phosphorus), gallium nitride, silicon nitride, etc.

However, it is difficult to machine these materials to small sized lenses having a large numerical aperture in the prior art.

[0006]

Also, many conventional lenses have irregular shapes. In order to align a plurality of lenses of such irregular shapes, high precision positioning in three-dimensional directions is necessary, so the load of the alignment work is large.

Also, when comprising a flying h ad (floating head) consisting of an optical head mounted on a swing arm, the

optical head can be prepared by separately preparing a slider and the lens and attaching them at a high precision, but in this case, the load of the attachment work and accordingly the load of preparation of the optical head is large.

[0007]

A first object of the present invention is to provide a method of production of an optical device capable of creating a small sized optical device, a second object is to provide a method of production of an optical device capable of creating an optical device having a small size and a large numerical aperture, a third object is to provide an optical device which can be created from the methods of production, and a fourth object is to provide an optical system comprising the related optical device.

[0008]

[Means for Solving the Problem]

An optical device according to the present invention is an optical device comprising a base material made of a first optical material and comprising a second optical material having a different refractive index from that of the first optical material, wher in the base material has a concavity and wher in the second optical mat rial is filled in this concavity.

[0009]

In the optical device according to the present invention, preferably the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and the base material has a second flat face located at an area around a circumferential edge of the concavity and a first flat face parallel or approximately parallel to the second flat face.

[0010]

In the optical device according to the present invention, more preferably the surface of the second optical material filled in the concavity and the second flat face are parallel or approximately parallel.

In the optical device according to the present invention, further preferably the surface of the second optical material filled in the concavity and the second flat face are located in an identical plane or approximately an identical plane.

[0011]

In the optical device according to the present invention, preferably the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and the shap of the surface of the concavity wh n the concavity is cut along its symm try axis is an arc or approximately an arc.

[0012]

In the optical device according to the present invention, preferably the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0013]

In the optical device according to the present invention, for example the second optical material is a liquid-like optical material and the surface of the base material forming the concavity is formed with a layer made of an optical material for sealing the concavity filled with the second optical material. In this case, the layer for sealing the concavity is made of for example a film having a constant or approximately constant thickness, and the second optical material is for example an optical oil or a liquid crystal.

[0014]

A first optical system according to the present invention is an optical system comprising first and second optical devices, wherein the first optical device has a first base mat rial made of a first optical material and has a second optical material having a diff rent refractive index from the first optical

material, the first base mat rial has a first concavity having a rotationally symmetric or approximately rotationally symmetric shape, the second optical material is filled in this first concavity, the second optical device has a second base material made of a third optical material and has a fourth optical material having a different refractive index from the third optical material, the second base material has a second concavity having a rotationally symmetric or approximately rotationally symmetric shape, the fourth optical material is filled in this second concavity, and the first and second optical devices are bonded so that symmetry axes of the first and second concavities are located on an identical straight line or approximately identical straight line.

[0015]

In the first optical system according to the present invention, preferably the first base material has a second flat face located at the area around the circumferential edge of the concavity and a first flat face parallel or approximately parallel with respect to the second flat face, the surface of the second optical material filled in the first concavity and the second flat face are located in an identical plane or approximately identical plane, the second base material

has a fourth flat face located at the area around the circumferential edge of the second concavity and a third flat face parallel or approximately parallel with respect to the fourth flat face, and one of the first and second flat faces is bonded with the third flat face.

[0016]

In the first optical system according to the present invention, more preferably the surface of the fourth optical material filled in the second concavity and the fourth flat face are parallel or approximately parallel.

In the first optical system according to the present invention, further preferably the surface of the fourth optical material filled in the second concavity and the fourth flat face are located in an identical plane or approximately identical plane.

[0017]

In the first optical system according to the present invention, preferably the first concavity is larger than the second concavity, the second flat face of the first base material and the third flat face of the second base material are bonded, the second optical material has a larger refractive index than the first optical material, the fourth optical material has a larger refractiv index than th third optical mat rial, and a solid imm rsion lens is comprised by the second optical material filled

in the first concavity and the fourth optical material filled in the second concavity.

[0018]

The first optical system according to the present invention can be used for example for a slider of an optical head attached to a swing arm. In this case, the third optical material is preferably made aluminum oxide.

[0019]

A second optical system according to the present invention is an optical system comprising an optical device and a lens, wherein the optical device has a base material made of a first optical material and has a second optical material having a different refractive index from the first optical material, the base material has a concavity having a rotationally symmetric or approximately rotationally symmetric shape, the second optical material is filled in this concavity, the lens is shaped by a rotationally symmetric or approximately rotationally symmetric curved face and the flat face, and the lens and the optical device are bonded so that the symmetry axis of the concavity and an optical axis of the lens are located on an identical straight line or approximately identical straight lin .

[0020]

In the second optical system according to th

present invention, preferably the base material has a second flat face located at the area around the circumferential edge of the concavity and a first flat face parallel or approximately parallel with respect to the second flat face, and the flat face of the lens and the first flat face of the optical device are bonded.

[0021]

In the second optical system according to the present invention, more preferably the surface of the second optical material filled in the concavity and the second flat face are parallel or approximately parallel.

In the second optical system according to the present invention, further preferably the surface of the second optical material filled in the concavity and the second flat face are located in an identical plane or approximately identical plane.

[0022]

In the second optical system according to the present invention, preferably the lens has a convex shape and is larger than the concavity, the second optical material has a larger refractive index than the first optical material, and the second optical material filled in the concavity and the lens comprise a solid immersion lens.

[0023]

The second optical system according to the pr sent invention can be used for example for a slider of an optical head attached to a swing arm. In this case, the first optical material is preferably made aluminum oxide.

[0024]

A first method of production of an optical device according to the present invention is a method of production of an optical device comprised of a concavity of a base material made of a first optical material filled with second optical material having a different refractive index from the first optical material, comprising a step of using a metallic mold formed with a projection projecting out into a cavity to mold the base material made of the first optical material with a concavity reproducing the shape of the projection and a step of filling the second optical material in the concavity of the molded base material.

[0025]

The first method of production of an optical device according to the present invention preferably further has a step of flattening the surface of the second optical material filled in the concavity.

[0026]

In the first method of production of an optical device according to the present invention, mor

preferably the projection has a rotationally symmetric or approximately rotationally symmetric shape, and in the flattening step, the surface of the second optical material is polished so that a flat plane vertical or approximately vertical with respect to the symmetry axis of the concavity reproducing the shape of the projection is formed.

[0027]

The first method of production of an optical device according to the present invention more preferably further has a step of polishing the base material so that a flat face parallel or approximately parallel to the surface of the flattened second optical material is formed.

[0028]

In the first method of production of an optical device according to the present invention, preferably the projection has a rotationally symmetric or approximately rotationally symmetric shape, and the shape of the surface of the projection when the projection is cut along its symmetry axis is an arc or approximately an arc.

[0029]

In the first method of production of an optical device according to the present inv ntion, pref rably the

second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0030]

In the first method of production of an optical device according to the present invention, for example, the second optical material is a liquid-like optical material, the step of filling the second optical material may have a step of filling the second optical material in the concavity of the molded base material and a step of sealing the concavity filled with the second optical material by a layer made of the optical material. In this case, the layer sealing the concavity is formed by for example a film having a constant or approximately constant thickness, and the second optical material is for example an optical oil or liquid crystal.

[0031]

A second method of production of an optical device according to the present invention is a method of production of an optical device comprised of a concavity of a base material made of a first optical material filled with a s cond optical material having a diff rent r fractive index from the first optical material, comprising a step of forming a resist having a hole in

the flat face of the base material made of the first optical material, a step of forming a concavity corresponding to the hole in the base material by etching, a step of removing a resist from the base material with the concavity formed therein, and a step of filling the second optical material in the concavity of the base material from which the resist is removed.

[0032]

The second method of production of an optical device according to the present invention preferably further has a step of flattening the surface of the second optical material filled in the concavity.

[0033]

In the second method of production of an optical device according to the present invention, more preferably the hole is circular or approximately circular, the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and in the flattening step, the surface of the second optical material is polished so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity is formed.

[0034]

The second method of production of an optical devic according to the pres nt invention more preferably

further has a step of polishing the base material so that a flat face parallel or approximately parallel with respect to the surface of the flattened second optical material is formed.

[0035]

In the second method of production of an optical device according to the present invention, preferably the hole is circular or approximately circular, the concavity has a rotationally symmetric or approximately rotationally symmetric shape, and the shape of the surface of the concavity in the case when the concavity is cut along its symmetry axis is an arc or approximately an arc.

[0036]

In the second method of production of an optical device according to the present invention, preferably the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0037]

In the second method of production of an optical device according to the present invention, for example, the second optical material is a liquid-like optical material, th step of filling the second optical material

may hav a step of filling the second optical material in the concavity of the base material from which the resist is removed and a step of sealing the concavity filled with the second optical material by a layer made of an optical material. In this case, the layer for sealing the concavity is formed by for example a film having a constant or approximately constant thickness, and the second optical material is made for example an optical oil or liquid crystal.

[0038]

A third method of production of an optical device according to the present invention is a method for manufacturing an optical device comprised of a concavity of a base material made of a first optical material filled with a second optical material having a different refractive index from the first optical material, comprising a step of forming on a second base material provided with a projection and having a flat area around the projection the first base material made of a layer of the first optical material burying the projection, a step of flattening the surface of the first base material to form a flat face and bonding the related flat face to a third base material made of a third optical material, a st p of removing the second base material from the first base material bond d to the third base material to expose

the concavity reproducing the shape of th projection in the first base material, and a step of filling the second optical material in the concavity of the exposed first base material.

[0039]

The third method of production of an optical device according to the present invention preferably further has a step of flattening the surface of the second optical material filled in the concavity.

[0040]

In the third method of production of an optical device according to the present invention, more preferably the projection has a rotationally symmetric or approximately rotationally symmetric shape, and in the flattening step, the surface of the second optical material is polished so that a flat face vertical or approximately vertical with respect to the symmetry axis of the concavity reproducing the shape of the projection is formed.

[0041]

The third method of production of an optical device according to the present invention more preferably further has a step of polishing the third base material so that a flat face parallel or approximat ly parallel to th surfac of th flattened s cond optical mat rial is

formed.

[0042]

In the third method of production of an optical device according to the present invention, preferably the projection has a rotationally symmetric or approximately rotationally symmetric shape, and the shape of the surface of the projection when the projection is cut along its symmetry axis is an arc or approximately an arc.

[0043]

In the third method of production of an optical device according to the present invention, preferably the first optical material and the third optical material are identical optical materials.

[0044]

In the third method of production of an optical device according to the present invention, preferably the second optical material is titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0045]

In the third method of production of an optical device according to the present invention, for example, the second optical material is a liquid-like optical

material, the step of filling the second optical material may have a step of filling the second optical material in the concavity of the exposed first base material and a step of sealing the concavity filled with the second optical material by a layer made of an optical material. In this case, the layer for sealing the concavity is formed by for example a film having a constant or approximately constant thickness, and the second optical material is made for example an optical oil or liquid crystal.

[0046]

In the first method of production of an optical device according to the present invention described above, the metallic mold has a projection projecting out into the cavity. By molding the base material by this metallic mold, a concavity reproducing the shape of the projection can be formed in the base material.

By filling the second optical material in the concavity of the base material made of the first optical material, light can be refracted at the surface of the concavity according to the difference of the refractive indexes. By reducing the size of the projection of the metallic mold, the concavity of th bas material can be reduced in sized and a small sized optical device can be created.

Also, by using a material having a large refractive index as the second material, for example, titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0047]

In the second method of production of an optical device according to the present invention described above, by forming a resist having a circular or approximately circular hole on the flat face of the base material made of the first optical material, a concavity corresponding to the hole can be formed by etching.

By removing the resist from the base material with the concavity formed therein and filling the second optical material in the concavity, the light can be refracted at the surface of the concavity according to the difference of the refractive indexes. By reducing the size of the hole, the concavity of the base material can be reduced in size, so a small sized optical device can be created.

Also, by using a material having a large refractive index as the second material, for example, titanium oxide, tantalum oxid , gallium phosphate, gallium

nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0048]

In the third method of production of an optical device according to the present invention, the second base material is provided with the projection and the area around the related projection is flat.

By forming on this second base material the first base material made of the first optical material for burying the projection, a concavity reproducing the shape of the projection can be formed in the first base material.

By flattening the surface of the first base material to form the flat face, bonding the related flat face to the third base material made of the third optical material, and removing the second base material from the first base material bonded to the third base material, a concavity reproducing the shape of the projection in the first base material can be exposed.

By filling the second optical material in the concavity of th first base material, light can be refracted at the surface of th concavity according to the difference of the refractive indexes. By reducing th

size of th proj ction of th second base material, the concavity of the first base material can be reduced in size and a small sized optical device can be created.

Also, by using a material having a large refractive index as the second material, for example, titanium oxide, tantalum oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0049]

[Embodiments of the Invention]

Below, embodiments of the present invention will be explained by referring to the attached drawings.

[0050]

Optical Device

Figure 1 is a schematic view of an embodiment of an optical device according to the present invention.

This optical device 100 has a parallelopiped or approximately parallelopiped shape. The optical device 100 has a base material (substrate) 101 and a lens 102.

The base material 101 and the lens 102 of the optical d vice 100 hav diff rent refractive indexes. Light can be r fracted at the boundary of the base material 101 and the lens 102. For example, when light is

made to enter an upper face 100U of the base material 101, the light emitted from a bottom face 100B can be converged (collected) or scattered by the lens 102 or can be changed to a parallel beam.

[0051]

The base material 101 has a rotationally symmetric or approximately rotationally symmetric concavity 101B in the bottom face of the base material 101. The shape of the surface of the concavity 101B when the concavity 101B is cut along its symmetric axis is preferably made an arc or approximately an arc.

The concavity 101B is filled with an optical material having a different refractive index from the base material 101. The lens 102 is comprised by the concavity 101B filled with that optical material.

[0052]

The bottom face of the lens 102 is flat or approximately flat and is parallel or approximately parallel to the upper face 100U of the optical device 100 (or the upper face of the base material 101). Also, the flat faces of the bottom face of the lens 102 and the bottom face of the base material 101 are parallel or approximat ly parallel and are preferably located in the id ntical plan . In Fig. 1, the flat faces of the bottom face of the lens 102 and the bottom face of the base

material 101 comprise the bottom face 100B of th optical device 100.

[0053]

When the material of the base material 101 is made for example quartz, and the material of the lens 102 is made for example silicon nitride, the lens 102 has a larger refractive index than the base material 101, so the function of a convex lens can be imparted to the lens 102.

Conversely, when the material of the base material 101 is made for example silicon nitride, and the material of the lens 102 is made for example quartz, the lens 102 has a smaller refractive index than the base material 101, so the function of a concave lens can be imparted to the lens 102.

[0054]

First Embodiment of Method of Production of Optical Device

Figure 2 and Fig. 3 are schematic explanatory views of a first embodiment of a method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical structur or approximat ly identical structure to the optical d vice 100 of Fig. 1.

[0055]

Figure 2(A) shows a metallic mold 3. This metallic mold 3 is formed with a passageway 4 through which a liquid-like or fluid-like optical material 6L passes and a cavity 3C. Also, a bottom portion of the metallic mold 3 is formed with a projection 5 projecting out into the cavity 3C. The area around the projection 5 is flat.

The projection 5 has an identical shape to the lens 102 of the optical device 100 of Fig. 1 and has a rotationally symmetric or approximately rotationally symmetric shape.

[0056]

In Fig. 2(B), the optical material 6L is injected into the cavity 3C from the passageway 4 of the metallic mold 3 to fill the optical material 6 in the cavity 3C. The optical material 6L injected is made for example molten quartz, a plastic, a synthetic resin, etc.

[0057]

In Fig. 2(C), the liquid-like optical material 6L is made to hardened to a solid optical material 6M, and a base material 6 made of the optical material 6M is taken out from the metallic mold 3. The concavity 6B is formed with the shape of the projection 5 transferred to the bottom portion of the bas material 6 taken out from the metallic mold 3. The area around the concavity 6B of the base material 6 is flat.

[0058]

In Fig. 3(D), an optical material 7M is filled in the concavity 6B of the bottom portion of the optical material 6. The optical material 7M has a different refractive index from the optical material 6, preferably has a larger refractive index than the optical material 6, and is made silicon nitride as an example.

For example, the optical material 7M is filled in the concavity 6B of the base material 6 by forming a layer 7 of the optical material 7M on the bottom portion of the base material 6 by sputtering or vapor deposition. In this case, a concavity 7B corresponding to the concavity 6B is formed in the layer 7.

[0059]

In Fig. 3(E), the bottom face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the bottom face of the layer 7 disappears. Preferably, the bottom face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 6B of the base material 6 is formed. Alternatively, the layer 7 is polished so that the flat face of the area around the the concavity 6B of the base material 6 and the bottom face of the lay r 7 b come parallel or approximately parallel.

By polishing the layer 7 so that the flat face at

the area around the concavity 6B of the base material 6 is exposed and further polishing the upper face of the base material 6 so as to become parallel or approximately parallel with respect to the flat face of the flattened layer 7, it is possible to obtain an optical device having the same structure as that of the optical device 100 of Fig. 1.

[0060]

Since the bottom portion of the metallic mold 3 has the projection 5 projecting out into the cavity 3C, the processing precision can be improved in comparison with a case of forming a concavity sunk into the cavity 3C and forming a convex lens by simple molding. In this way, by using the metallic mold 3, it is possible to prepare a small sized convex lens having a higher processing precision than a convex lens obtained by simple molding.

[0061]

Note that it is also possible to mold the lens by using an upper mold and a lower mold in place of the metallic mold shown in Figs. 2(A) and 2(B). The projection is formed at the bottom portion of the lower mold, and the area around the this projection is flat. This projection is identical to the proj ction 5 of Figs. 2(A) and 2(B).

First, by injecting an optical material (for exampl

a glass material) into the cavity between the upper mold and the lower mold and simultaneously heating the glass material, the lower mold, and the upper mold to a predetermined temperature, the glass material is softened. Then, the softened glass material is pressed by the upper mold.

Next, the glass material, the lower mold, and the upper mold are cooled to cause the glass material to harden and the base material 6 is taken out from the metallic molds. The concavity 6B is formed with the shape of the projection at the bottom portion of the lower mold transferred to the bottom portion of this base material 6 taken out from the metallic molds.

In this way, it is also possible to obtain the base material 6 shown in Fig. 2(C).

[0062]

Second Embodiment of Method of Production of Optical Device

Figure 4 and Fig. 5 are schematic explanatory views of a second embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having the identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0063]

In Fig. 4(A), a resist 9 is formed on th flat face of a silicon substrate 8 - an example of the base material. The size of the bottom face of the resist 9 is made identical or approximately identical to the size of the bottom face of the lens 102 in Fig. 1.

[0064]

In Fig. 4(B), the resist 9 is used as a mask to etch the surface of the silicon substrate 8 to form the projection 8U. The shape of the projection 8U is identical to the shape of the lens 102 and is a rotationally symmetric or approximately rotationally symmetric shape. For the etching, use is made of for example ion milling, RIE, or the like. Note that, in Fig. 4(B), it is also possible to etch utilizing an undercut.

[0065]

In Fig. 4(C), an optical material 10M is laminated on the surface of the silicon substrate 8 where the projection 8U is formed so as to bury the projection 8U and thereby form a base material made of a layer 10 of the optical material 10M. It is also possible to form the layer 10 by for example sputtering or vapor deposition.

When the layer 10 is formed on the silicon substrate 8, a projection 10U corresponding to the proj ction 8U is formed on the upper face of th lay r 10.

[0066]

In Fig. 4(D), the upper fac of the layer 10 is flattened. For example, it is polished so that the projection 10U of the upper face of the layer 10 disappears. Preferably, the upper face of the layer 10 is polished so that a flat face vertical with respect to the symmetry axis of the projection 8U of the silicon substrate 8 is formed. Alternatively, the layer 10 is polished so that the flat face at the area around the projection 8U of the silicon substrate 8 and the upper face of the layer 10 become parallel or approximately parallel.

[0067]

In Fig. 4(E), the flat face of a base material 11 made of an optical material 11M is bonded to a flattened upper face 10S of the layer 10. As the bonding method, for example, it is possible to bond by a transparent adhesive or possible to bond by anodic bonding. The optical material 11M is preferably made the same material as the optical material 10M.

[0068]

In Fig. 5(F), the silicon substrate 8 bonded to the bottom face of the layer 10 of Fig. 4(E) is removed to expos the bottom face of the layer 10. It is also possible to dissolv the silicon substrate 8 by for example an aqueous solution of potassium hydroxide to

remov it.

The shape of the projection 8U of the silicon substrate 8 is transferred to the bottom face of the layer 10, whereby a concavity 10B corresponding to the projection 8U is formed.

[0069]

In Fig. 5(G), the optical material 7M is filled in the concavity 10B of the bottom face of the layer 10. The optical material 7M has a different refractive index from the optical material 10M, preferably has a larger refractive index than the optical material 10M. Silicon nitride is used as an example.

For example, a layer 7 of the optical material 7M is formed on the bottom face of the layer 10 by sputtering or vapor deposition to fill the optical material 7M in the concavity 10B of the layer 10. In this case, a concavity 7B corresponding to the concavity 10B is formed in the layer 7.

[0070]

In Fig. 5(H), the bottom face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the bottom face of the layer 7 disapp ars. Pr ferably, the bottom face of the layer 7 is polished so that a flat fac vertical with resp ct to the symmetry axis of the concavity 10B of the layer 10 is

formed. Alternatively, the layer 7 is polished so that the flat face at the area around the concavity 10B of the layer 10 and the bottom face of the layer 7 become parallel or approximately parallel.

By polishing the layer 7 so that the flat face at the area around the concavity 10B of the layer 10 is exposed and further polishing the upper face of the base material 11 so as to become parallel or approximately parallel with respect to the polished face of the layer 7 or by removing the base material 11, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0071]

<u>Third Embodiment of Method of Production of Optical Device</u>

Figure 6 and Fig. 7 are schematic explanatory views of a third embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0072]

In Fig. 6(A), a resist 19 is formed at the flat fac of a silicon substrate 18 - an xample of the base

material. The size of the bottom face of the r sist 19 is made identical to the size of the bottom face of the lens 102 in Fig. 1.

[0073]

In Fig. 6(B), an optical material 20M is laminated on the surface of the silicon substrate 18 with the resist 19 formed thereon to bury the resist 19 and thereby form a base material made of a layer 20 of the optical material 20M. It is also possible to form a layer 20 of the optical material 20M by for example sputtering or vapor deposition. It is also possible to use for example aluminum oxide as the optical material 20M.

When the layer 20 is formed on the silicon substrate 18, a projection 20U of a shape in accordance with the resist 19 is formed on the surface of the layer 20.

[0074]

In Fig. 6(C), the upper face of the layer 20 is flattened. For example, it is polished so that the projection 20U of the upper face of the layer 20 disappears. Preferably, the upper face of the layer 20 is polished so that a flat face vertical with respect to the symmetry axis of the resist 19 on the silicon substrate 18 is formed. Alternatively, the layer 20 is polish d so that the flat face at the area around the r sist 19 on the silicon substrate 18 and the upper face of the layer

20 become parallel or approximately parallel.

[0075]

In Fig. 6(D), the flat face of a base material 21 made of an optical material 21M is bonded to an upper face 20S of the layer 20. As the bonding method, for example, it is also possible to bond by a transparent adhesive or possible to bond by anodic bonding. The optical material 21M is preferably made the same material as the optical material 20M.

[0076]

In Fig. 7(E), the silicon substrate 18 and the resist 19 bonded to the bottom face of the layer 20 of Fig. 6(D) are removed to expose the bottom face of the layer 20. It is also possible to dissolve the silicon substrate 18 by for example an aqueous solution of potassium hydroxide to remove it. It is also possible to dissolve and remove the resist 19 by for example a resist use peeling solution or an organic solvent (for example acetone).

The shape of the resist 19 is transferred to the bottom face of the layer 20, whereby a concavity 20B corresponding to the shape of the resist 19 is formed.

[0077]

In Fig. 7(F), an optical material 7M is filled in th concavity 20B of the bottom fac of th layer 20. The

optical material 7M has a different refractive index from the optical material 20M, preferably has a larger refractive index than the optical material 10M. Silicon nitride is used as an example.

For example, by forming a layer 7 of the optical material 7M on the bottom face of the layer 20 by sputtering or vapor deposition, the optical material 7M is filled in the concavity 20B of the layer 20. In this case, a concavity 7B corresponding to the concavity 20B is formed in the layer 7.

[0078]

In Fig. 7(G), the bottom face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the bottom face of the layer 7 disappears. Preferably, the bottom face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 20B of the layer 20 is formed. Alternatively, the layer 7 is polished so that the flat face at the area around the the concavity 20B of the layer 20 and the bottom face of the layer 7 become parallel or approximately parallel.

By polishing the layer 7 so that the flat face at the area around the concavity 20B of the layer 20 is exposed and furth r polishing the upper face of the base material 21 so as to become parallel or approximately

parallel with respect to th polished face of the lay r 7 or by removing the base material 21, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0079]

<u>Fourth Embodiment of Method of Production of Optical Device</u>

Figure 8 and Fig. 9 are schematic explanatory views of a fourth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0080]

In Fig. 8(A), a resist 29 is formed on the flat face of a base material 31 made of an optical material 31M. The optical material 31M is made for example quartz.

A circular or approximately circular hole 29H is formed in the resist 29 on the base material 31.

[0081]

In Fig. 8(B), the base material 31 with the resist 29 formed thereon is immersed in an etching solution 32 for a pr det rmined time. Th etching solution 32 is compris d of for example a fluoric acid solution

corroding quartz.

By immersing the base material 31 in the etching solution 32 for a predetermined time, the base material 31 is gradually corroded from the hole 29H of the resist 29, and a concavity 31U is formed on the lower side of the hole 29. The size of this concavity 31U is made identical to the size of the lens 102 in Fig. 1.

[0082]

In Fig. 9(C), the base material 31 is taken out from the etching solution 32, and the resist 29 is removed. It is also possible to dissolve and remove the resist 29 by a resist use peeling solution or organic solvent (for example acetone) etc.

[0083]

In Fig. 9(D), an optical material 27M is filled in the concavity 31U of the upper face of the base material 31. The optical material 27M has a different refractive index from the optical material 31M, preferably has a larger refractive index than the optical material 31M. Silicon nitride is used as an example.

For example, by forming a layer 27 of the optical material 27M on the upper face of the base material 31 by sputtering or vapor deposition, the optical material 27M is fill d in the concavity 31U of the base material 31. In this cas , a concavity 27U corresponding to the

concavity 31U is formed in the layer 27.

[0084]

In Fig. 9(E), the upper face of the layer 27 is flattened. For example, it is polished so that the concavity 27U of the upper face of the layer 27 disappears. Preferably, the upper face of the layer 27 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 31U of the base material 31 is formed. Alternatively, the layer 27 is polished so that the flat face at the area around the the concavity 31U of the base material 31 and the upper face of the layer 27 become parallel or approximately parallel.

By polishing the layer 27 so that the flat face at the area around the concavity 31U of the base material 31 is exposed and further polishing the bottom face of the base material 31 so as to become parallel or approximately parallel with respect to the polished face of the layer 27, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0085]

<u>Fifth Embodiment of Method of Production of Optical Device</u>

Figure 10 is a schematic explanatory view of a fifth

embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0086]

In Fig. 10(A), a base material 41 having a concavity 41U is shown. The concavity 41U has a rotationally symmetric or approximately rotationally symmetric shape. The area around the concavity 41U in the base material 41 is flat. The base material 41 is made of an optical material 41M.

The size of the concavity 41U is identical to the size of the lens 102 in Fig. 1.

As this base material 41, use is made of for example the base material 6 in Fig. 2(C), the base material 11 with the layer 10 bonded thereto in Fig. 5(F), the base material 21 with the layer 20 bonded thereto in Fig. 7(E), or the base material 31 in Fig. 9.

[0087]

In Fig. 10(B), an optical material 37M having a different refractive index from the optical material 41M is filled in the concavity 41U of the upper face of the base material 41.

As an example, when th optical material 41M is not

quartz, a gelated quartz is used as th optical material 37M and coated on the upper face of the base material 41 to form a layer 37 of the optical material 37M and fill the optical material 37M in the concavity 41U of the base material 41.

Then, the base material 41 with the optical material 37M filled in the concavity 41U is heated to cause the optical material 37M to cure.

[0088]

In Fig. 10(C), the upper face of the hardened layer 37 is flattened. For example, it is polished so that any surface roughness or undulation of the upper face of the optical material 37 disappears. Preferably, the upper face of the layer 37 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 41U of the base material 41 is formed. Alternatively, the layer 37 is polished so that the flat face at the area around the concavity 41U of the base material 41 and the upper face of the layer 37 become parallel or approximately parallel.

By polishing the layer 37 so that the flat face at the area around the concavity 41U of the base material 41 is expos d and furth r polishing the bottom face of the base material 41 so as to becom parallel or approximately parallel with respect to the polished face

of the layer 37, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0089]

Sixth Embodiment of Method of Production of Optical Device

Figure 11 is a schematic explanatory view of a sixth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or approximately identical configuration to the optical device 100 of Fig. 1.

[0090]

In Fig. 11(A), a base material 51 having a concavity 51U is shown. The concavity 51 has a rotationally symmetric or approximately rotationally symmetric shape. The area around the concavity 51U in the base material 51 is flat. The base material 51 is made of an optical material 51M.

The size of the concavity 51U is identical to the size of the lens 102 in Fig. 1.

As this base material 51, us is made of for example the base material 6 in Fig. 2(C), th base material 11 with the layer 10 bond d ther to in Fig. 5(F), the base

material 21 with the layer 20 bonded thereto in Fig. 7(E), or the base material 31 in Fig. 9.

[0091]

In Fig. 11(B), a liquid-like optical material 47M having a different refractive index from the optical material 51M is filled in the concavity 51U of the upper face of the base material 51. As the optical material 47M, use is made of an optical liquid for example an optical oil or liquid crystal.

Then, a layer 48 made of an optical material 48M is formed on the upper face of the base material 51 to seal the concavity 51U filled with the optical material 47M by the layer 48. In this way, the liquid-like optical material 47M can be filled in the concavity 51U. The layer 48 can be formed as a film having a constant or approximately constant thickness too. Note that by polishing the bottom face of the base material 51, the base material 51 can be reduced to an intended thickness.

[0092]

First Embodiment of Optical System

Figure 12 is a schematic view of the configuration of a first embodiment of an optical system using an optical d vice according to th present invention.

This optical system 119 has optical d vic s 100 and 110 having identical configurations and comprised by

stacking the optical devices 100 and 110. Note that the optical device 100 is identical or approximately identical to the optical device 100 of Fig. 1, so the explanation thereof is appropriately omitted.

[0093]

The optical device 110 has a base material 111 and a lens 112. The base material 111 is made of an optical material. The base material 111 and the lens 112 have different refractive indexes.

The base material 111 has a rotationally symmetric or approximately rotationally symmetric concavity 111B in the bottom face of the base material 111. The shape of the surface of the concavity 111B when the concavity 111B is cut along its symmetry axis is preferably made an arc or approximately an arc.

The concavity 111B is filled with an optical material having a different refractive index from the base material 111. The lens 112 is comprised by the concavity 111B filled with the related optical material.

[0094]

The bottom face of the lens 112 is flat and is parallel or approximately parallel to an upper face 110U of the optical device 110 (or the upper face of the base material 111). Also, the flat faces of the bottom face of the lens 112 and the bottom face of th base material 111

are located in the identical plane and comprise a bottom face 110B of the optical device 110.

[0095]

The base material 111, lens 112, upper face 110U, and bottom face 110B of the optical device 110 correspond to the base material 101, lens 102, upper face 100U, and bottom face 100B of the optical device 100.

[0096]

The optical device 110 has a parallelopiped or approximately parallelopiped shape. When light is made to enter an upper face 100U, the light emitted from a bottom face 100B can be converged (collected) or scattered by the lens 102 or can be changed to a parallel beam.

The bottom face 100B of the optical device 100 and the upper face 110U of the optical device 110 are bonded so that the optical axes of the lenses 102 and 112 are located on the identical straight line or approximately identical straight line.

[0097]

It is also possible to form the optical devices 100 and 110 in a plate-like or approximately plate-like shape. It is possible to stack the optical devices 100 and 110 while positioning them with a high precision.

For example, by adding positioning marks like the marks for mask alignment used when semiconductor

integrated circuits ar manufactured on the base materials 101 and 111, it is possible to use these marks to stack a plurality of optical devices with a high precision.

[0098]

Also, by making the shapes of the optical devices 100 and 110 parallelepipeds or approximately parallelepipeds or plate-like or approximately plate-like, it is possible to prevent inclination of (the optical axes of) the lenses from occurring when the optical devices are stacked, the optical devices can be stacked while positioning them in the two-dimensional direction (vertical and lateral directions), and it is possible to easily prepare the optical system 119.

[0099]

Second Embodiment of Optical System

Figure 13 is a schematic view of the configuration of a second embodiment of an optical system using optical devices according to the present invention. Note that the optical device 100 in Fig. 13 is identical or approximately identical to the optical device 100 of Fig. 1, so the explanation thereof will be appropriately omitted.

This optical system 129 has optical devices 100 and 120 and is comprised by stacking the optical devices 100

and 120.

[0100]

The optical device 120 has a base material 121 and a lens 122. The base material 121 is made of an optical material. The base material 121 and the lens 122 have different refractive indexes.

The base material 121 has a rotationally symmetric or approximately rotationally symmetric concavity 121B in the bottom face of the base material 121. The shape of the surface of the concavity 121B when the concavity 121B is cut along its symmetry axis is preferably made an arc or approximately an arc.

The concavity 121B is filled with an optical material having a different refractive index from the base material 121. The lens 122 is comprised by the concavity 121B filled with the related optical material.

[0101]

The bottom face of the lens 122 is flat and is parallel or approximately parallel to an upper face 120U of the optical device 120 (or the upper face of the base material 121). Also, the flat faces of the bottom face of the lens 122 and the bottom face of the base material 121 ar located in th identical plane and comprise a bottom face 120B of the optical d vice 120.

[0102]

The optical device 120 has a parallelopiped or approximately parallelopiped shape. When light is made to enter an upper face 120U, the light emitted from a bottom face 120B can be converged (collected) or scattered by the lens 122 or can be changed to a parallel beam.

The bottom face 100B of the optical device 100 and the upper face 120U of the optical device 120 are bonded so that the optical axes of the lenses 102 and 122 are located on the identical straight line or approximately identical straight line.

[0103]

It is also possible to form the optical devices 100 and 120 to be plate-like or approximately plate-like. It is possible to stack the optical devices 100 and 120 while positioning them with a high precision.

Also, by making the shapes of the optical devices 100 and 120 parallelopiped or approximately parallelopiped or plate-like or approximately plate-like, it is possible to prevent inclination of (the optical axes of) the lenses from occurring in the case where the optical devices are stacked and it is possible to easily prepare the optical system 129.

Also, a solid immersion lens (SIL) can be comprised by the optical system 129, and it is possible to obtain a high numerical aperture.

[0104]

Third Embodiment of Optical System

Figure 14 is a schematic view of the configuration of a third embodiment of an optical system using optical devices according to the present invention. Note that, in an optical system 129A of Fig. 14, identical reference numerals are assigned to identical components as those of the optical system 129 of Fig. 13. Explanations of the identical components will be appropriately omitted.

This optical system 129A is configured as the optical system 129 of Fig. 13 without the base material 101.

[0105]

This optical system 129A has a lens 102 and an optical device 120 and is comprised by stacking the lens 102 on the optical device 120. The bottom face of the lens 102 contacts the upper face 120U of the optical device 120.

By comprising the optical system 129A by the lens 102 and the optical device 120 in this way, the optical system 129A can be reduced in size in comparison with the optical system 129 of Fig. 13. Also, a solid immersion l ns (SIL) can b comprised by the optical system 129A.

[0106]

It is possible to obtain the optical system 129A of

Fig. 14 from the optical system 129 of Fig. 13.

For example, when the material of the base material 101 of the optical device 100 is quartz, the material of the lens 102 is gallium nitride, the material of the base material 121 of the optical device 120 is aluminum oxide, and the material of the lens 122 is gallium nitride, it is possible to immerse the optical system 129 of Fig. 13 in an etching solution such as fluoric acid to dissolve and remove the base material 101 and thus obtain the optical system 129A of Fig. 14.

[0107]

Also, it is possible to take out the lens 102 from the optical device 100.

For example, when the material of the lens 102 is gallium nitride and the material of the base material 101 is quartz, it is possible to immerse the optical device 100 in an etching solution of fluoric acid or the like to dissolve the base material 101 and take out the lens 102.

[0108]

Fourth Embodiment of Optical System

Figure 15 is a schematic view of the configuration of a fourth embodiment of an optical system using optical d vices according to the present invention. Note that, in an optical syst m 149 of Fig. 15, id ntical reference numerals are assigned to identical components as those of

th optical system 129 of Fig. 13. Explanations of the identical components will be appropriately omitted.

[0109]

This optical system 149 has optical devices 100, 120, and 140. The optical device 100 is stacked upon the optical device 120, and the optical device 140 is stacked upon the optical device 100.

The upper face of the optical device 100 of the optical system 129 and a bottom face 140B of the optical device 140 are bonded so that the optical axes of the lenses 102, 122, and 142 of the optical devices 100, 120, and 140 are located on the identical straight line or approximately identical straight line.

[0110]

The optical device 140 has a base material 141 and the lens 142. The base material 141 is made of an optical material. The base material 141 and the lens 142 have different refractive indexes.

The base material 141 has a rotationally symmetric or approximately rotationally symmetric concavity 141B in the bottom face of the base material 141. The shape of the surface of the concavity 141B when the concavity 141B is cut along its symmetry axis is pref rably made an arc or approximately an arc.

The concavity 141B is filled with an optical

material having a different refractive index from the base material 141. The lens 142 is comprised by the concavity 141B filled with the related optical material.

[0111]

The bottom face of the lens 142 is flat and is parallel or approximately parallel to an upper face 140U of the optical device 140 (or the upper face of the base material 141). Also, the flat faces of the bottom face of the lens 142 and the bottom face of the base material 141 are located in the identical plane and comprise a bottom face 140B of the optical device 140.

[0112]

The optical device 140 has a parallelopiped or approximately parallelopiped shape. When light is made to enter an upper face 140U, the light emitted from a bottom face 140B can be converged (collected) or scattered by the lens 142 or can be changed to a parallel beam.

This optical device 140 has the function of the collimator lens and changes the laser beam from a semiconductor laser 60 to a parallel beam and supplies the same to the optical device 100.

[0113]

The optical system 129 has th optical devices 100 and 120. By the combination of th optical devices 100 and 120, a high numerical aperture NA can be obtained,

and a solid immersion lens (SIL) can be comprised. By enlarging the refractive index of the lens 122, the numerical aperture NA of the optical system 129 can be made higher.

In the optical devices 100, 120, and 140, the lenses 102, 122, and 142 are formed by utilizing the concavities of the base materials 101, 121, and 141, so the range of selection of the materials of the lenses 102, 122 and 142 can be enlarged, and optical materials having large refractive indexes can be used as the materials of the lenses 102, 122, and 142.

[0114]

The parallel beam from the optical device 140 passes through the lenses 102 and 122 and is emitted from the bottom face of the lens 122. The emitted beam is focused on a recording surface of an optical disc 80 to irradiate the recording surface.

Note that, by rounding the edges of the bottom face of the optical device 120 (face facing the optical disc 80), it is possible to reduce collisions with and/or shock to the surface of the optical disc 80.

[0115]

<u>Fifth Embodiment of Optical System</u>

Figur 16 is a sch matic view of the configuration of a fifth mbodiment of an optical system using optical

devic s according to the present invention. Note that, in an optical system 149A of Fig. 16, identical reference numerals are assigned to identical components as those of the optical system 149 of Fig. 15. Explanations of the identical components will be appropriately omitted.

This optical system 149A is configured as the optical system 149 of Fig. 15 without the base material 141.

[0116]

The optical system 149A has the optical devices 100 and 120 and the lens 142. The optical device 100 is stacked upon the optical device 120, and the lens 142 is stacked upon the optical device 100. The optical devices 100 and 120 and the lens 142 are bonded so that the optical axes of the lenses 102 and 122 of the optical devices 100 and 120 and the lens 142 are located on the identical straight line or approximately identical straight line.

The lens 142 comprises a collimator lens and changes the laser beam from a semiconductor laser 60 to a parallel beam and supplies the same to the optical device 100.

[0117]

The parallel beam from the lens 142 passes through the lenses 102 and 122 and is emitted from the bottom

face of th lens 122. The emitted b am is focused on the recording surface of an optical disc 80 to irradiate the related recording surface.

By comprising the optical system 149A by the optical devices 100 and 120 and the lens 142 in this way, the optical system 149A can be reduced in size in comparison with the optical system 149 of Fig. 15. Note that a distance between the lens 142 and the semiconductor laser 60 can be adjusted by the shape and thickness of the lens 142.

[0118]

Sixth Embodiment of Optical System

Figure 17 is a schematic view of the configuration of a sixth embodiment of an optical system using optical devices according to the present invention. Note that, in an optical system 159 of Fig. 17, identical reference numerals are assigned to identical components as those of the optical system 149 of Fig. 15. Explanations of the identical components will be appropriately omitted.

This optical system 159 is configured as the optical system 149 of Fig. 15 with an optical device 150 inserted as a beam splitter between the optical devices 100 and 140.

[0119]

The optical system 159 has optical d vices 100, 120,

140, and 150. The optical device 100 is stacked upon th optical device 120, the optical device 150 is stacked upon the optical device 100, and the optical device 140 is stacked upon the optical device 150. The optical devices 100, 120, 140, and 150 are bonded so that the optical axes of the lenses 102, 122, and 142 of the optical devices 100, 120. and 140 are located on the identical straight line or approximately identical straight line.

[0120]

The optical device 150 located between the optical devices 100 and 140 has the function of a beam splitter. A film which is semi-transparent (semi-transparent film) 152 is located between the lenses 102 and 142.

This semi-transparent film 152 passes the parallel beam from (the lens 142 of) the optical device 140 therethrough and reflects a returned beam from (the lens 102 of) the optical system 129.

[0121]

The optical device 140 has the function of a collimator lens. It changes the laser beam from a semiconductor laser 60 to a parallel beam and supplies this parallel beam via the optical device 150 to th optical devic 100 in the optical system 129.

[0122]

The optical system 129 emits the parallel beam from the optical device 150 through the lenses 102 and 122 from the bottom face of the lens 122 and focuses the emitted beam on the recording surface of the optical disc 80 to irradiate the related recording surface. Also, the optical system 129 supplies the reflected laser beam (returned laser beam) reflected at (the recording surface of) the optical disc 80 to the optical device 150.

By interposing the optical device 150 as a beam splitter between the optical device 140 and the optical system 129, it is possible to take out the reflected laser beam reflected at the optical disc 80 from the side face of the optical device 150.

[0123]

Seventh Embodiment of Optical System

Figure 18 is a schematic view of the configuration of a seventh embodiment of an optical system using optical devices according to the present invention. Note that, in an optical system 159A of Fig. 18, identical reference numerals are assigned to identical components as those of the optical system 159 of Fig. 17. Explanations of the identical components will be appropriately omitt d.

This optical system 159A is configured as the optical system 159 of Fig. 17 without the base material

141.

[0124]

The optical system 159A has the optical devices 100, 120, and 150 and the lens 142. The optical device 100 is stacked upon the optical device 120, the optical device 150 is stacked upon the optical device 100, and the lens 142 is stacked upon the optical device 150.

The optical devices 100, 120, and 150 and the lens 142 are bonded so that the optical axes of the lenses 102 and 122 of the optical devices 100 and 120 and the lens 142 are located on the identical straight line or approximately identical straight line.

The lens 142 comprises a collimator lens. It changes the laser beam from a semiconductor laser 60 to a parallel beam and supplies this parallel beam via the optical device 150 to the optical device 100.

[0125]

The parallel beam from the lens 142 passes through the lenses 102 and 122 and is emitted from the bottom face of the lens 122. The emitted beam is focused on the recording surface of the optical disc 80 to irradiate the related recording surface. Also, the optical system 129 supplies th reflected las r beam (returned laser beam) reflect d at (the recording surfac of) th optical disc 80 to th optical device 150.

By comprising the optical system 159A by th optical devices 100, 120, and 150 and the lens 142 in this way, the optical system 159A can be reduced in size in comparison with the optical system 159 of Fig. 17.

[0126]

First Embodiment of Optical Head

Figure 19 is a schematic view of the configuration of a first embodiment of an optical head using optical devices according to the present invention.

This optical head 500 has an optical system 329 and a mirror 61. A flying head is comprised by a swing arm 62 and a suspension 63.

[0127]

The optical system 329 has optical devices 300 and 320. The optical device 300 is stacked upon the optical device 320. This optical system 329 comprises a slider. The bottom face 320B of the optical device 320 of the optical system 329 and the surface of the optical disc 80 face each other. The bottom face 320B of the optical device 320 comprises a slider face.

In this way, there is an advantage that the optical system 329 can be used for the slider of the optical head 500 as it is.

[0128]

A mirror 61 is attached to th upper face of the

swing arm 62. The suspension 63 is attached to the bottom face of the swing arm 63, or the suspension 63 is formed.

Also, a through hole 62H for allowing the reflected beam of the mirror 61 to pass therethrough is formed in the swing arm 62.

The optical system 329 is attached to the front end of the suspension 63.

[0129]

The mirror 61 is supplied with the laser beam of the parallel beam from the base side of the swing arm 62, reflects the supplied laser beam, and supplies the same via the through hole 62H to the optical system 329.

The optical system 329 collects the laser beam from the mirror 61 by using lenses 302 and 322 and focuses it on the recording surface of the optical disc 80. Also, the optical system 329 returns the laser beam reflected at the recording surface of the optical disc 80 (returned laser beam) via the through hole 62H to the mirror 61.

The mirror 61 reflects the returned laser beam from the optical system 329 and returns it to the base side of the swing arm 62.

[0130]

Figure 20 is a schematic view of th configuration of th optical system 329 in Fig. 19.

Th optical device 300 has a bas material 301 and

the lens 302. The base material 301 is made of an optical material. The base material 301 and the lens 302 are different in refractive index.

The base material 301 has a rotationally symmetric or approximately rotationally symmetric concavity 301B in the bottom face of the base material 301. The shape of the surface of the concavity 301B when the concavity 301B is cut along its symmetry axis is preferably made an arc or approximately an arc.

The concavity 301B is filled with an optical material having a different refractive index from the base material 301. The lens 302 is comprised by the concavity 301B filled with the related optical material.

[0131]

The bottom face of the lens 302 is flat and is parallel or approximately parallel to an upper face 300U of the optical device 300 (or the upper face of the base material 301). Also, the flat faces of the bottom face of the lens 302 and the bottom face of the base material 301 are located in the identical plane and comprise a bottom face 300B of the optical device 300.

[0132]

The optical devic 300 exhibits a parallelopiped or approximately parall lopiped shape. When light nters the upper face 300U, the beam emitted from the bottom face

300B can be conv rged (collected) by the lens 302.

[0133]

The optical device 320 has a base material 321 and the lens 322. The base material 321 is made of an optical material. The base material 321 and the lens 322 are different in refractive index.

The base material 321 has a rotationally symmetric or approximately rotationally symmetric concavity 321B in the bottom face of the base material 321. The shape of the surface of the concavity 321B when the concavity 321B is cut along its symmetry axis is preferably made an arc or approximately an arc.

The concavity 321B is filled with an optical material having a different refractive index from the base material 321. The lens 322 is comprised of the concavity 321B filled with the related optical material.

[0134]

The bottom face of the lens 322 is flat and is parallel or approximately parallel to an upper face 320U of the optical device 320 (or the upper face of the base material 321). Also, the flat faces of the bottom face of the lens 322 and the bottom face of the base material 321 are located in the identical plane and comprise the bottom face 320B of the optical device 320.

[0135]

The optical device 320 exhibits a parallelopip d or approximately parallelopiped shape. When light enters the upper face 320U, the beam emitted from the bottom face 320B can be converged (collected) by the lens 322.

The bottom face 300B of the optical device 300 and the upper face 320U of the optical device 320 are bonded so that the optical axes of the lenses 302 and 322 are located on the identical straight line or approximately identical straight line.

Note that, by rounding the edges of the bottom face (face facing the optical disc 80) 320B of the optical device 320, it is possible to reduce collisions with and/or impact to the surface of the optical disc 80.

[0136]

The optical system 329 of the optical head 500 desirably has a large rigidity and/or hardness. By forming the base material 321 of the optical device 320 by aluminum oxide, the rigidity and/or hardness can be increased.

A high numerical aperture can be obtained by the optical system 329. By comprising a solid immersion lens (SIL) by the optical system 329 and using the related optical syst m 329 in th n ar field region, it is possible to perform near field optical recording and/or reproduction and it is possible to improve a recording

density of the optical disc.

[0137]

It is also possible to form rails for floating the optical system 329 as the slider on the bottom face 320B of the optical device 320.

It is also possible to form a coil generating a magnetic field (or a magnetic flux) at the time of opto-magnetic recording when the optical disc 80 is an opto-magnetic disc.

It is also possible to easily prepare the rails and/or coil of the bottom face 320B of the optical device 320 by forming the optical device 320 in a parallelopiped or approximately parallelopiped or plate-like or approximately plate-like shape by utilizing a semiconductor manufacturing process.

[0138]

As an example, the size of the optical system 329 in a lateral direction is made about 1 mm, the size in a vertical direction is made about 0.5 mm, and the size in a height direction is made about 0.4 mm.

As an example, the size of the optical device 300 in the height direction is made about 0.3 mm, and the size of the optical device 320 in the height direction is made about 0.13 mm.

As an example, a diameter of th bottom face (or the

flat fac) of the lens 302 is made about 0.2 mm, and the diameter of the bottom face (or the flat face) of the lens 322 is made about 0.1 mm.

[0139]

Second Embodiment of Optical Head

Figure 21 is a schematic view of the configuration of a second embodiment of an optical head using optical devices according to the present invention. Note that, identical reference numerals are assigned to identical components as those of the optical head 500 of Fig. 19 and the optical system 329 of Fig. 20. Explanations of the identical components will be appropriately omitted.

This optical head 500A is configured as the optical head 500 of Fig. 19 without the base material 301 and with an optical system 329A attached to the suspension 63.

[0140]

The optical head 500A has an optical system 329A and a mirror 61. A flying head is comprised by the swing arm 62 and the suspension 63.

The optical system 329A is configured as the optical system 329 of Fig. 19 and Fig. 20 with the base material 301 is removed.

This optical system 329A has an optical device 320 and a l ns 302. The lens 302 is stacked upon the optical

device 320. Also, th optical system 329A comprises a slider, the bottom face 320B of the optical device 320 of the optical system 329A and the surface of the optical disc 80 face each other, and the bottom face 320B of the optical device 320 comprises a slider face.

[0141]

The mirror 61 is attached to the upper face of the swing arm 62. The suspension 63 is attached to the bottom face of the swing arm, or the suspension 63 is formed.

Also, a through hole 62H through which the reflected beam of the mirror 61 may pass is formed in the swing arm 62.

The optical device 320 of the optical system 329A is attached to the front end of the suspension 63.

[0142]

The mirror 61 is supplied with the laser beam of the parallel beam from the base side of the swing arm 62, reflects the supplied laser beam, and supplies the same via the through hole 62H to the optical system 329A.

The optical system 329A collects the laser beam from the mirror 61 by using the lenses 302 and 322 and focuses it on the recording surface of the optical disc 80. Also, the optical system 329A r turns the laser b am reflect d at the recording surface of the optical disc 80 (returned laser b am) via the through hole 62H to the mirror 61.

The mirror 61 reflects the returned laser beam from the optical system 329A and returns it to the base side of the swing arm 62.

[0143]

Figure 22 is a schematic view of the configuration of the optical system 329A in Fig. 21.

The upper face of the lens 302 exhibits a rotationally symmetric or approximately rotationally symmetric curved shape.

The bottom face of the lens 302 is flat and is bonded to the upper face 320U of the optical device 320 (or the upper face of the base material 321).

[0144]

The lens 302 and the optical device 320 are bonded so that the optical axes of the lenses 302 and 322 are located on the identical straight line or approximately identical straight line. Note that, by rounding the edges of the bottom face (face facing the optical disc 80) 320B of the optical device 320, it is possible to reduce collision with and/or impact to the surface of the optical disc 80.

[0145]

Third Embodiment of Optical Head

Figur 23 is a schematic view of the configuration of a third embodiment of an optical head using optical

devices according to the present invention.

This optical head 600 has an optical system 329, an IC chip 74, a prism 75. and an optical device 340. A flying head is comprised by a swing arm 72 and a suspension 73.

[0146]

The optical system 329 has the optical devices 300 and 320. The optical device 300 is stacked upon the optical device 320. This optical system 329 comprises a slider, the bottom face 320B of the optical device 320 of the optical system 329 and the surface of the optical disc 80 face each other, and the bottom face 320B of the optical device 320 comprises the slider face.

The optical system 320 has an identical configuration to the optical system 329 shown in Fig. 19 and Fig. 20. Explanations thereof will be appropriately omitted.

[0147]

The suspension 73 is attached to the bottom face of the swing arm 72, or the suspension 73 is formed.

Also, the upper face of the IC chip 74 is bonded to the front end of the bottom face of the swing arm 72, and a not illustrated signal line and power supply line are disposed along th swing arm 72. Electric power can b suppli d to the IC chip 74 by the pow r supply lin ,

while an output signal of the IC chip 74 can be taken out and a signal can be supplied to the IC chip 74 by the signal line.

[0148]

The upper face of the prism 75 and the upper face of a seat 76 are bonded to the bottom face of the IC chip 74.

The upper face of the optical device 340 is bonded to the bottom face of the prism 75.

An optical fiber 71 is bonded to the bottom face of the seat 76. For example, a V-shaped groove is formed in the bottom face of the seat 76, and the optical fiber 71 is bonded by the adhesive so that the optical fiber is inserted in the V-shaped groove. Note that, the seat 76 is desirably made of an identical material to that for the IC chip 74.

The optical system 329 is attached to the front end of the suspension 73.

[0149]

The optical device 340 has a base material 341 and a lens 342. The base material 341 is made of an optical material. The base material 341 and the lens 342 are diff rent in refractive index.

The base material 341 has a rotationally symmetric or approximately rotationally symmetric concavity in th

bottom face of the bas material 341. The shape of the surface of the concavity when the concavity is cut along its symmetry axis is preferably made an arc or approximately an arc. The concavity is filled with an optical material having a different refractive index from the base material 341. The lens 342 is comprised by the concavity filled with the related optical material.

[0150]

The bottom face of the lens 342 is flat and is parallel or approximately parallel to an upper face 340U of the optical device 340 (or the upper face of the base material 341). Also, the flat faces of the bottom face of the lens 342 and the bottom face of the base material 341 are located in the identical plane and comprise a bottom face 340B of the optical device 340.

[0151]

The optical device 340 exhibits a parallelopiped or approximately parallelopiped shape. When light enters the upper face 340U, the beam emitted from the bottom face 340B of the optical device 340 can be changed to a parallel beam by the lens 342.

[0152]

The inclined face of the prism 75 r flects th laser beam output from the optical fib r 71 and suppli s the same to th optical device 340.

Th optical device 340 changes the las r beam from the prism 75 to a parallel beam and supplies the same to the optical system 329.

[0153]

The optical system 329 collects the laser beam from the optical device 340 by using the lenses 302 and 322 and focuses it to the recording surface of the optical disc 80. Also, the optical system 329 returns the laser beam reflected at the recording surface of the optical disc 80 (returned laser beam) via the optical device 340 to the prism 75.

The prism 75 passes the returned laser beam from the optical system 329 therethrough and supplies the same to the IC chip 74.

[0154]

The IC chip 74 is an optical semiconductor composite device. A photo-detector and a processing circuit are formed on the bottom face of the IC chip 74, or the photo-detector and the processing circuit are attached.

The photo-detector receives the returned laser beam and supplies a reception light signal in accordance with the returned laser beam to the processing circuit.

The processing circuit performs the predetermined processing based on the reception light signal from the photo-d tector and creates a signal indicating the result

of th processing. This signal can be taken out from the signal line connected to the IC chip 74.

[0155]

Fourth Embodiment of Optical Head

Figure 24 is a schematic view of the configuration of a fourth embodiment of an optical head using optical devices according to the present invention. Note that, identical reference numerals are assigned to identical components as those of the optical head 600 of Fig. 23 and the optical system 329A of Fig. 21 and Fig. 22. Explanations of the identical components will be appropriately omitted.

This optical head 600A is configured as the optical head 600 of Fig. 23 without the base material 301 and with the optical system 329A attached to the suspension 73.

[0156]

The optical head 600A has the optical system 329A, IC chip 74, prism 75, and the optical device 340. A flying head is comprised by the swing arm 72 and the suspension 73.

The optical system 329A has an identical configuration to the optical system 329A of Fig. 21 and Fig. 22. The optical device 320 of the optical system 329A is attached to the front end of the suspension 73.

[0157]

The inclined face of the prism 75 reflects the laser beam output from the optical fiber 71 and supplies the same to the optical device 340.

The optical device 340 changes the laser beam from the prism 75 to a parallel beam and supplies the same to the optical system 329A.

[0158]

The optical system 329A collects the laser beam from the optical device 340 by using the lenses 302 and 322 and focuses it on the recording surface of the optical disc 80. Also, the optical system 329A returns the laser beam reflected at the recording surface of the optical disc 80 (returned laser beam) via the optical device 340 to the prism 75.

The prism 75 passes the returned laser beam from the optical system 329A therethrough and supplies the same to the IC chip 74.

[0159]

Note that the refractive index of the glass used in the mold lens is 1.4 to 1.7 as an example.

As the optical material of the optical device according to th present invention, particularly the optical material having a large refractive ind x (or a high refractive index) filled in the concavity of the

base material, use can be made of for example aluminum oxide (Al_2O_3 having a refractive index of for example about 1.8), titanium oxide (TiO_2 having a refractive index of for example about 2.5), tantalum oxide (Ta_2O_5 having a refractive index of about 2.4), or gallium phosphate (GaP having a refractive index of for example about 3.3) By using the above optical materials, an optical device having a large numerical aperture can be prepared.

[0160]

Also, as the optical material of the optical device according to the present invention, particularly the optical material filled in the concavity of the base material, use can be made of compounds such as $Ta_{X1}O_{Y1}$, $Ti_{X2}O_{Y2}$, $Al_{X3}O_{Y3}$, $Si_{X4}O_{Y4}$, $Si_{X5}N_{Y5}$, $Mg_{X6}F_{Y6}$, $Ga_{X7}N_{Y7}$, $Ga_{X8}P_{Y8}$, $Ti_{X9}Nb_{Y9}O_{Z9}$, and $Ti_{Z6}Ta_{Z7}O_{Z8}$. Note X1 to X9, Y1 to Y9, and Z6 to Z9 are numerals enabling the above compounds.

[0161]

Note that the above embodiments are illustrations of the present invention. The present invention is not limited to the above embodiments.

[0162]

[Effects of the Invention]

As explained above, according to the m thod of production of an optical device according to the present

invention, it is possible to prepar a small sized optical device. Also, according to the method of production of an optical device according to the present invention, it is possible to prepare an optical device having a small size and large numerical aperture.

Also, according to the present invention, an optical device which can be prepared from the above method of production and an optical system using the related optical device can be provided.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A schematic view of the configuration of an embodiment of an optical device according to the present invention.

[Fig. 2]

A schematic explanatory view of a first embodiment of a method of production of an optical device according to the present invention.

[Fig. 3]

A schematic explanatory view of the first embodiment of the method of production of an optical device according to the present invention continued from Fig. 2.

[Fig. 4]

A schematic xplanatory view of a second embodim nt of the method of production of an optical device

according to th present invention.

[Fig. 5]

A schematic explanatory view of the second embodiment of the method of production of an optical device according to the present invention continued from Fig. 4.

[Fig. 6]

A schematic explanatory view of a third embodiment of the method of production of an optical device according to the present invention.

[Fig. 7]

A schematic explanatory view of the third embodiment of the method of production of an optical device according to the present invention continued from Fig. 6.

[Fig. 8]

A schematic explanatory view of a fourth embodiment of the method of production of an optical device according to the present invention.

[Fig. 9]

A schematic explanatory view of the fourth embodiment of the method of production of an optical device according to the present invention continued from Fig. 8.

[Fig. 10]

A schematic explanatory view of a fifth embodiment

of the method of production of an optical device according to the present invention.

[Fig. 11]

A schematic explanatory view of a sixth embodiment of the method of production of an optical device according to the present invention.

[Fig. 12]

A schematic view of the configuration of a first embodiment of an optical system using an optical device according to the present invention.

[Fig. 13]

A schematic view of the configuration of a second embodiment of an optical system using optical devices according to the present invention.

[Fig. 14]

A schematic view of the configuration of a third embodiment of an optical system using optical devices according to the present invention.

[Fig. 15]

A schematic view of the configuration of a fourth embodiment of an optical system using optical devices according to the present invention.

[Fig. 16]

A schematic vi w of the configuration of a fifth embodim nt of an optical system using optical devices

according to the present invention.

[Fig. 17]

A schematic view of the configuration of a sixth embodiment of an optical system using optical devices according to the present invention.

[Fig. 18]

A schematic view of the configuration of a seventh embodiment of an optical system using optical devices according to the present invention.

[Fig. 19]

A schematic view of the configuration of a first embodiment of an optical head using optical devices according to the present invention.

[Fig. 20]

A schematic view of the configuration of an optical system 329 in Fig. 19.

[Fig. 21]

A schematic view of the configuration of a second embodiment of an optical head using optical devices according to the present invention.

[Fig. 22]

A schematic view of the configuration of an optical syst m 329A in Fig. 21.

[Fig. 23]

A schematic view of the configurati n of a third

embodiment of an optical h ad using optical devices according to the present invention.

[Fig. 24]

A schematic view of the configuration of a fourth embodiment of an optical head using optical devices according to the present invention.

[Description of References]

3... metallic mold, 4... passageway, 5, 8U, 10U... projections, 6, 11, 21, 31, 41, 51, 101, 111, 121, 141, 301, 321... base materials, 6B, 7B, 10B, 20B, 101B, 27U, 31U, 41U, 51U, 101B, 111B... concavities, 6L, 6M, 7M, 10M, 11M, 20M, 21M, 27M, 31M, 37M, 41M, 47M, 48M, 51M... optical materials, 7, 10, 20, 27, 37, 48... layers, 8, 18... silicon substrates, 9, 19, 29, 103... resists, 10S, 100U, 110U, 120U, 140U... upper faces, 29H, 103H... holes, 32... etching solution, 60... semiconductor laser, 61... mirror, 62, 72... swing arms, 62H... through hole, 63, 73... suspensions, 71... optical fiber, 74... IC chip, 75... prism, 76... seat, 80... optical disc, 100, 110, 120, 140, 340... optical devices, 100B, 110B, 120B, 140B... bottom faces, 102, 112, 122, 142, 302, 322... lenses, 119, 129, 129A, 149, 149A, 159, 159A, 329, 329A... optical systems, 500, 500A, 600, 600A... optical heads.

DOCUMENT NAME DRAWINGS

Fig. 1

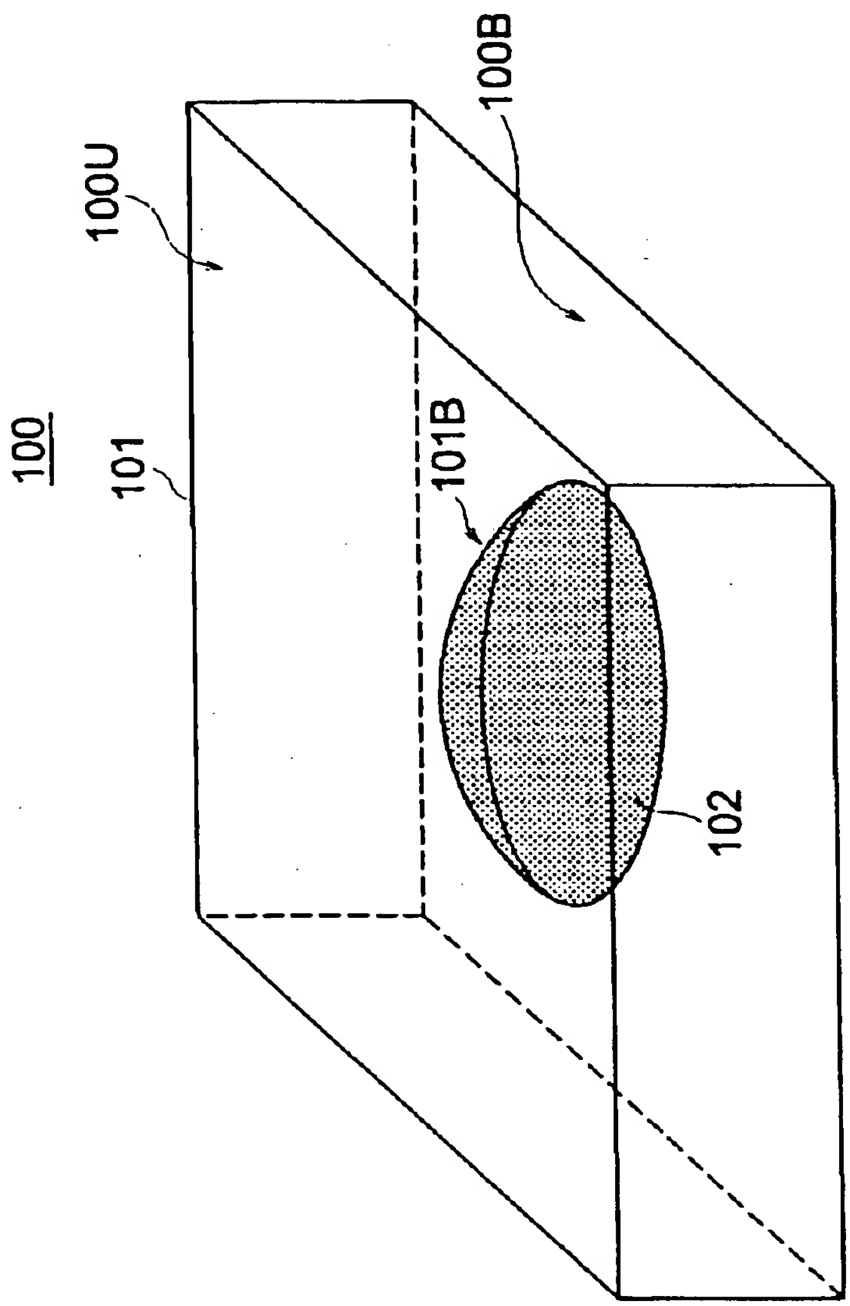


Fig. 2

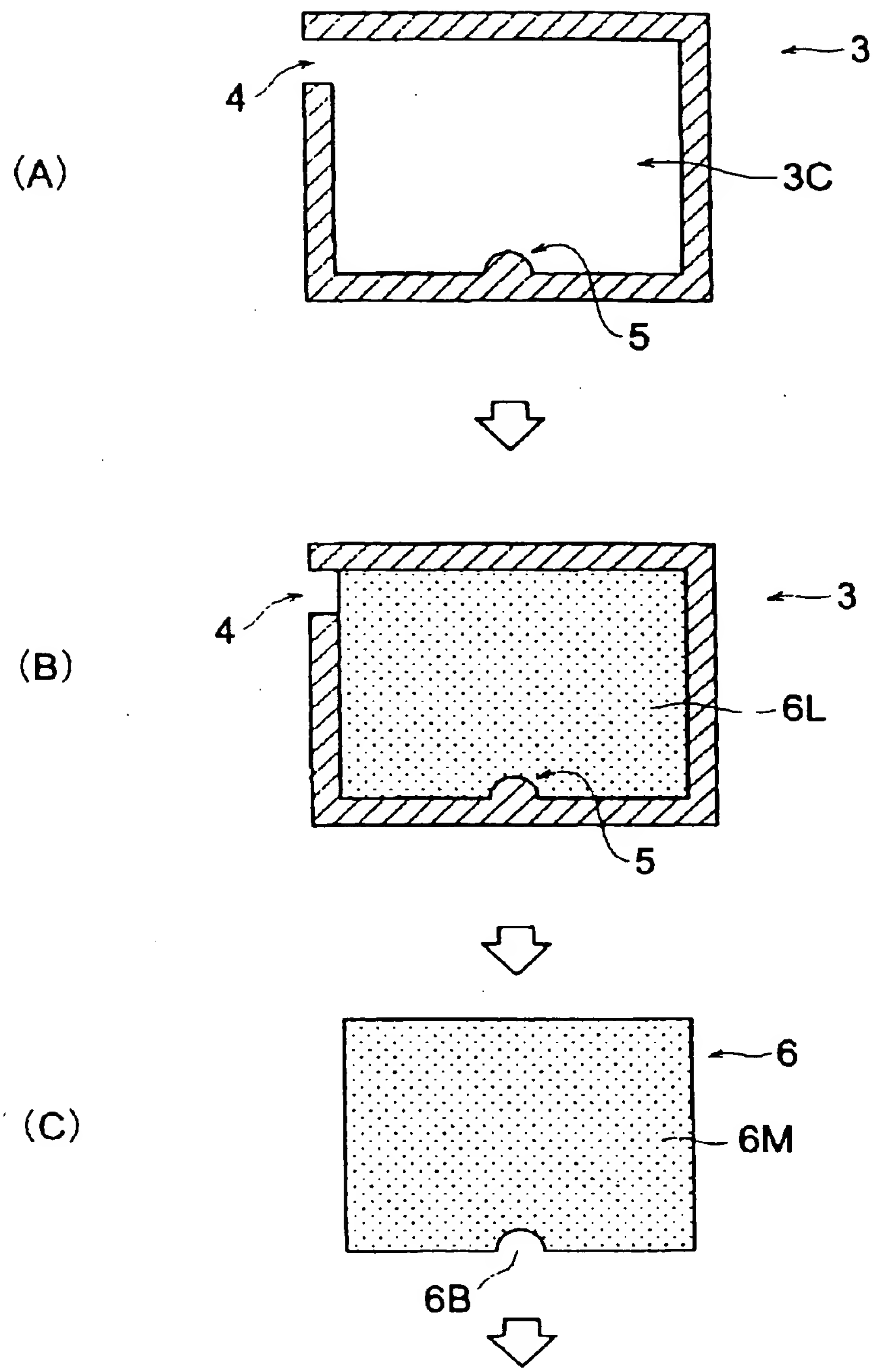


Fig. 3

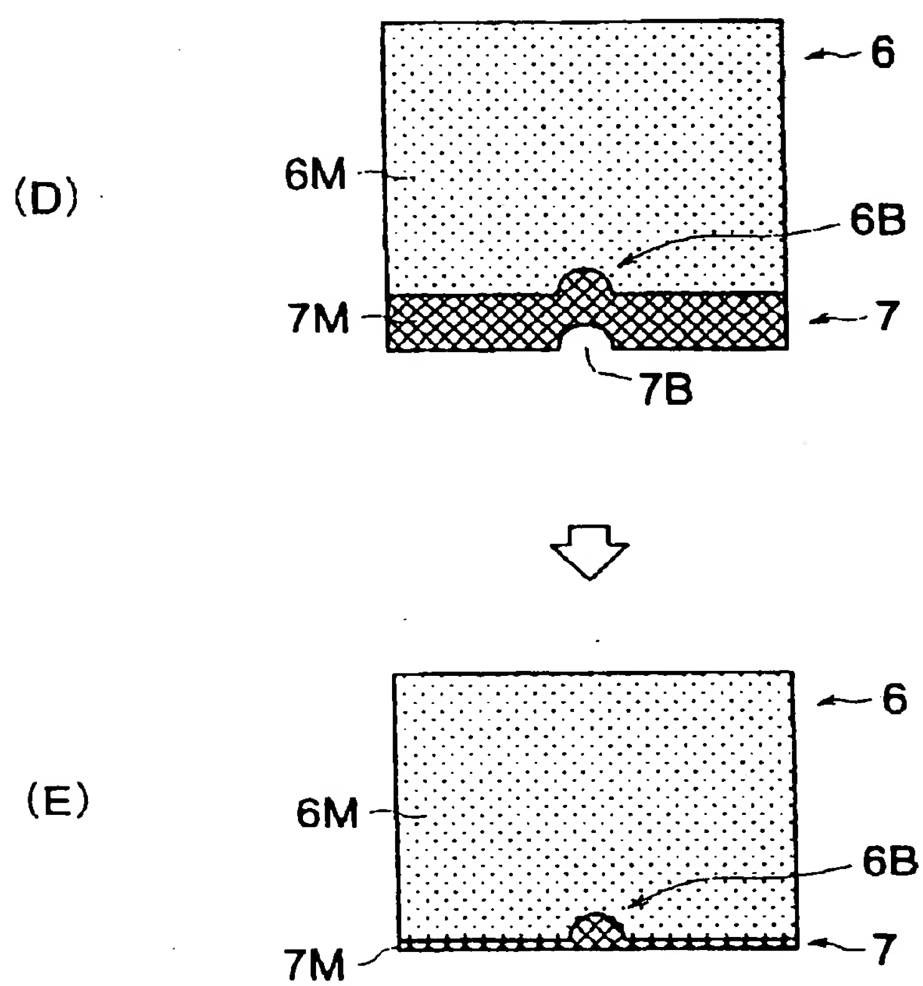


Fig. 4

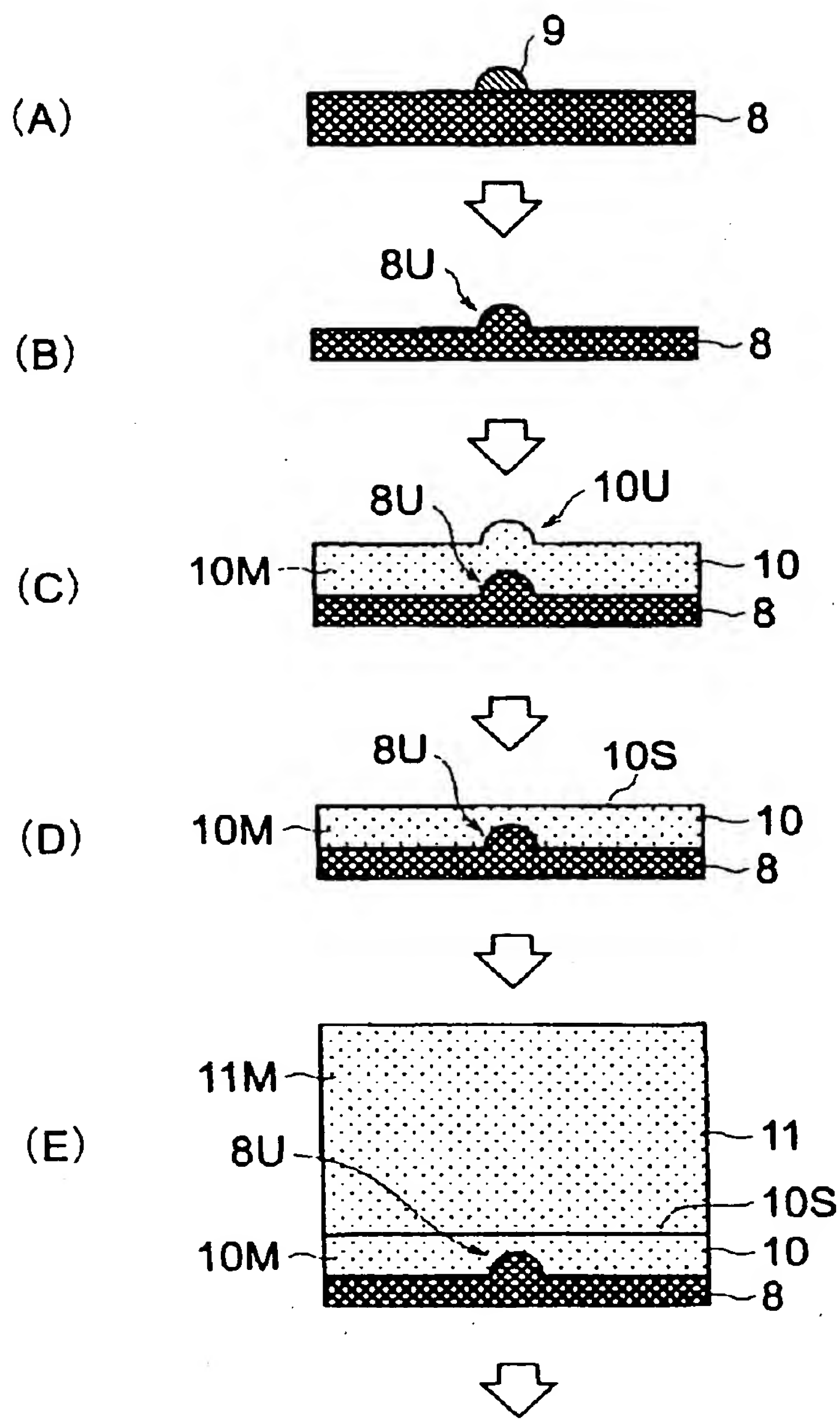


Fig. 5

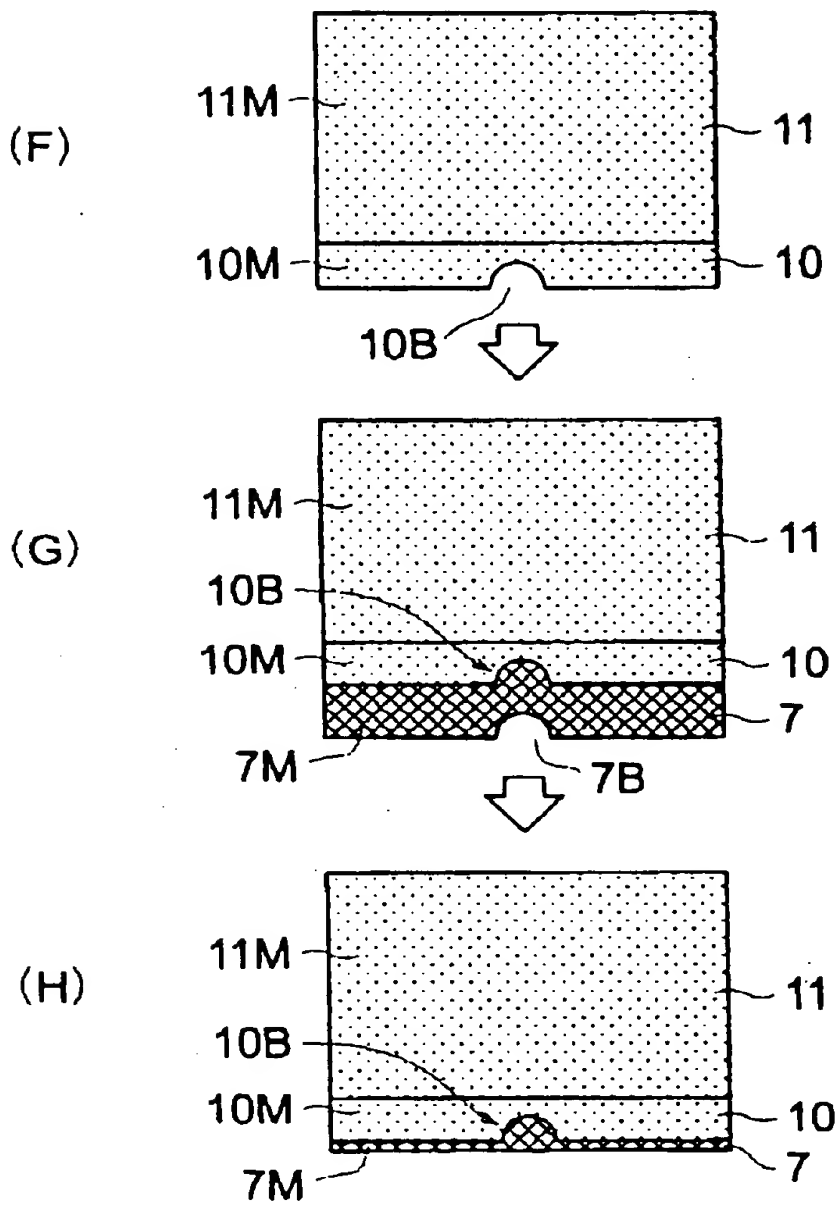

(F)
11M
11
10M
10
10B
(G)
11M
11
10B
10M
10
7
7M
7B
(H)
11M
11
10B
10M
10
7M
7

Fig. 6

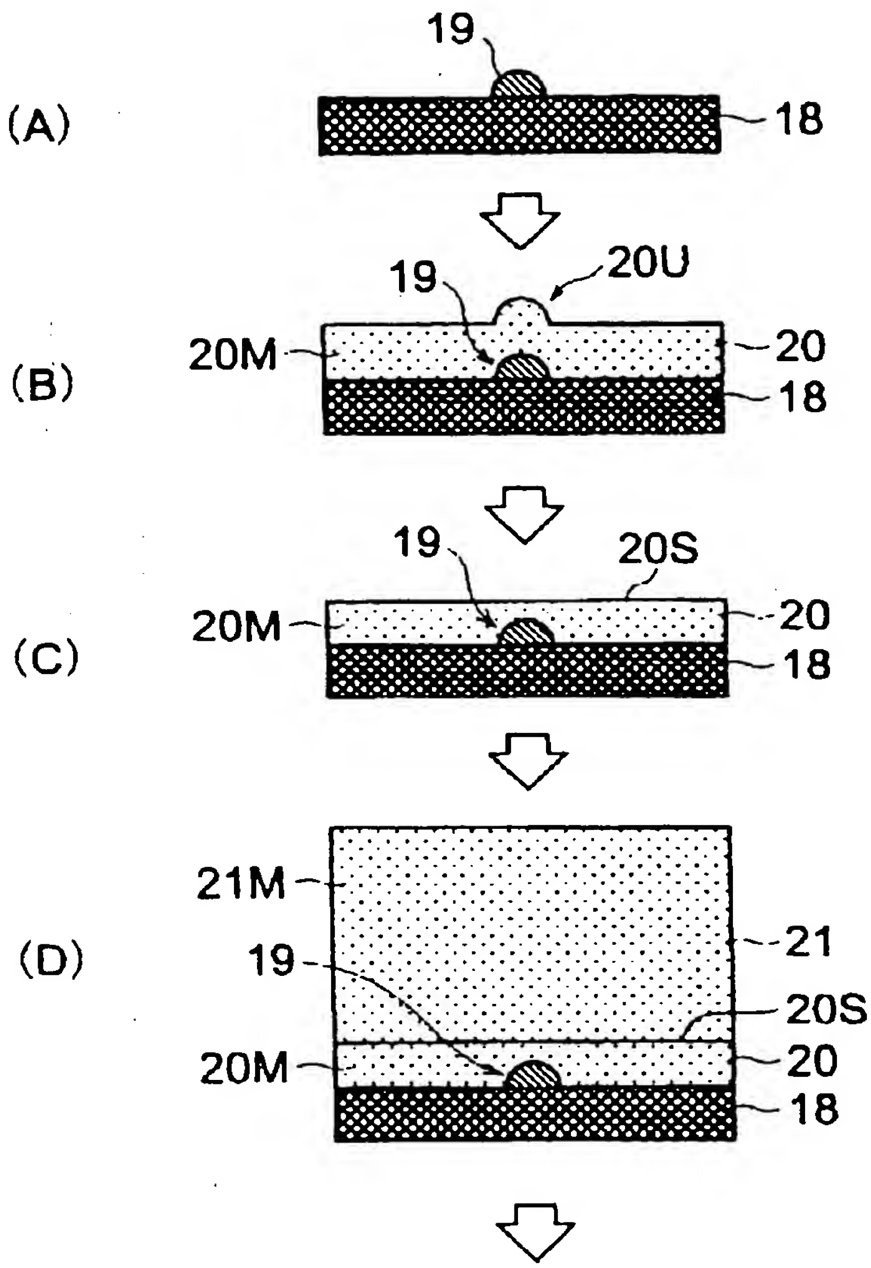
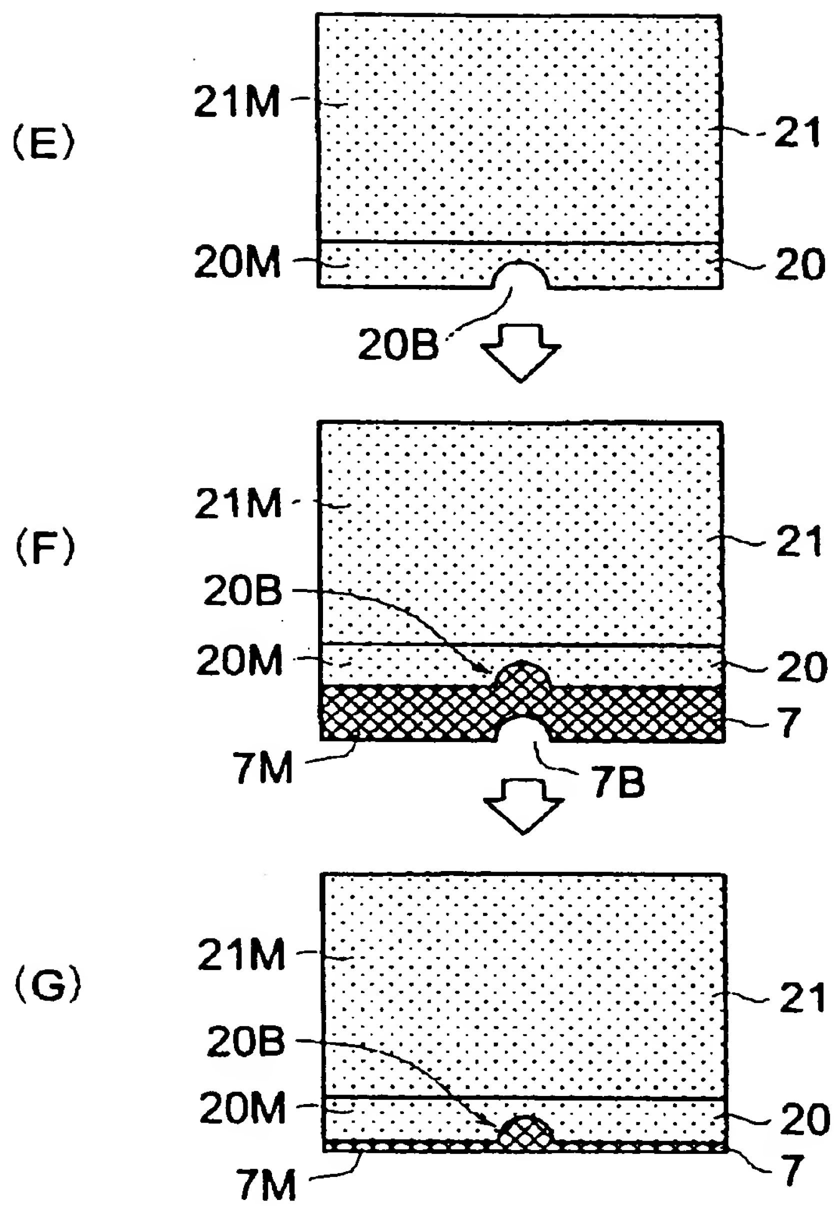


Fig. 7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21
20M
20
20B
(F)
21M
21
20B
20M
20
7
7M
7B
(G)
21M
21
20B
20M
20
7M
7

Fig. 8

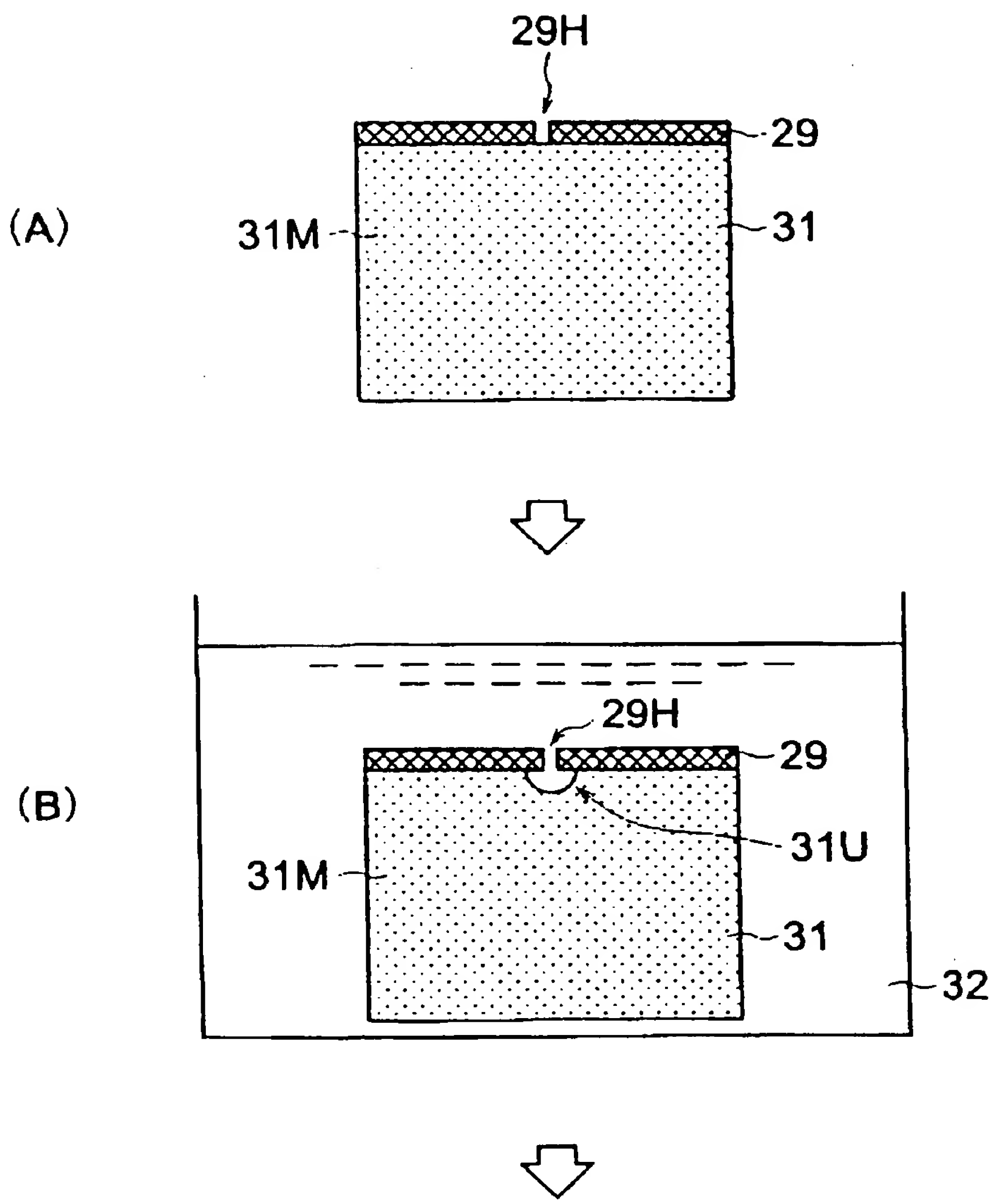
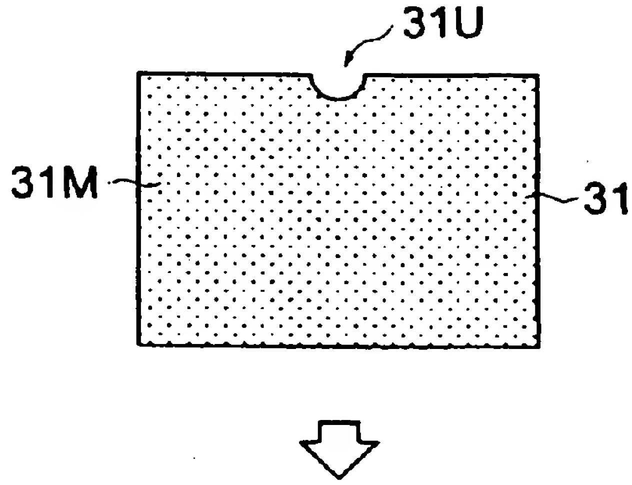
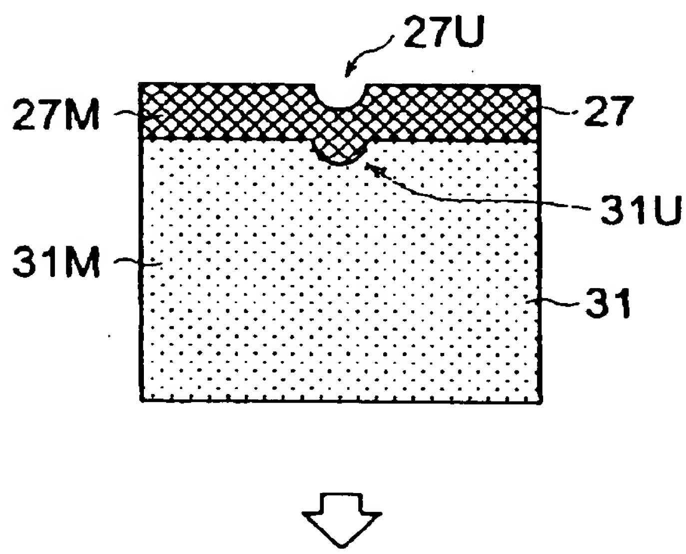


Fig. 9

(C)



(D)



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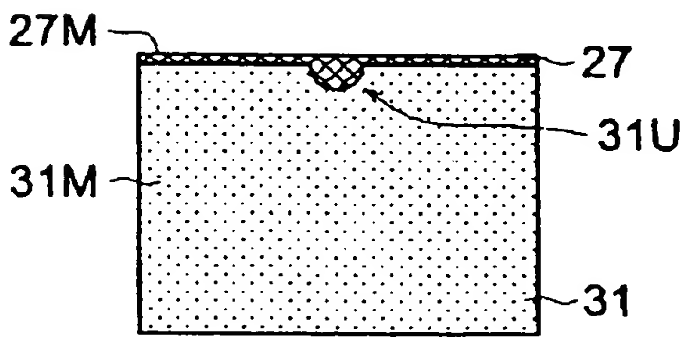


Fig. 10

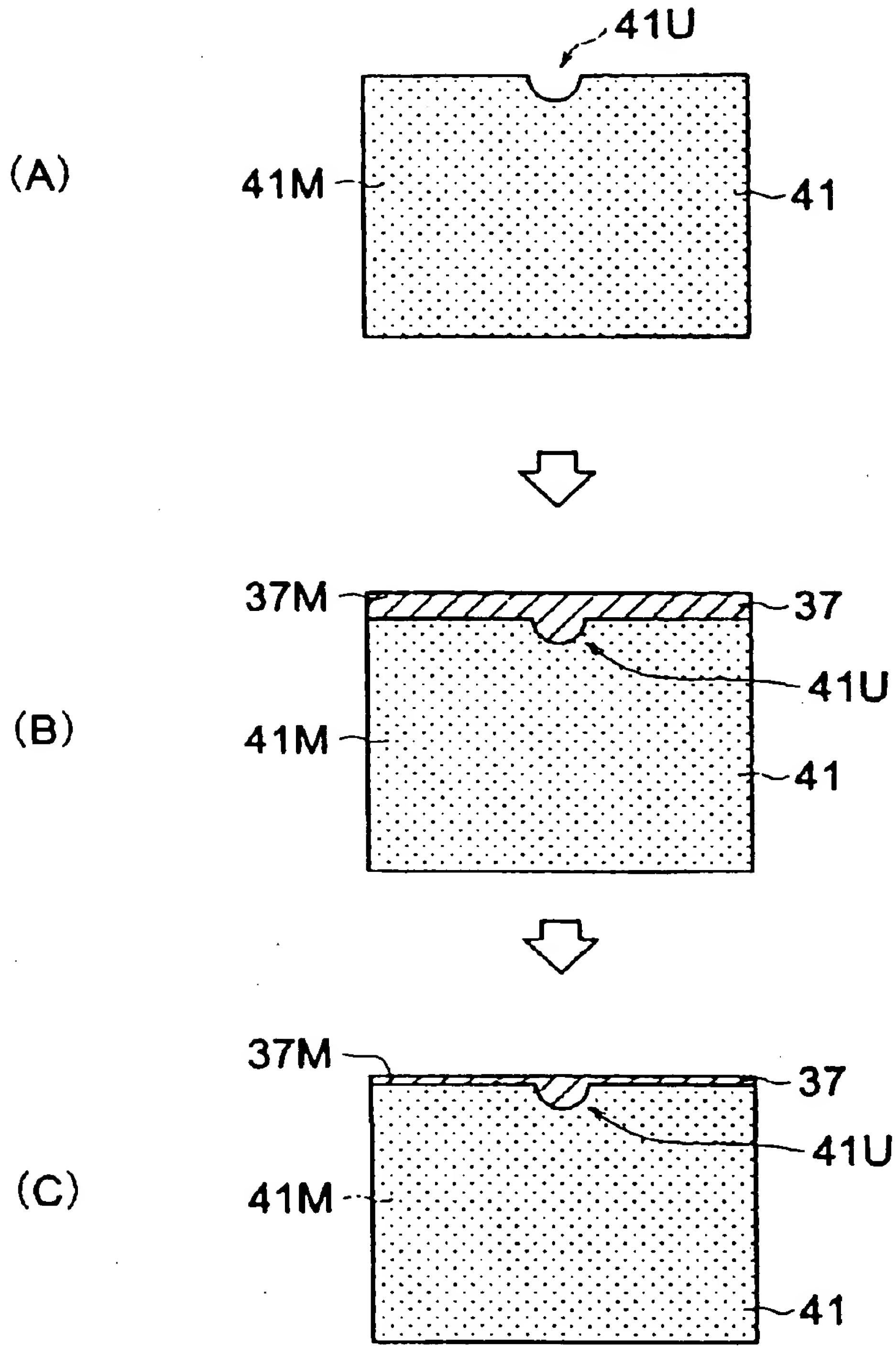
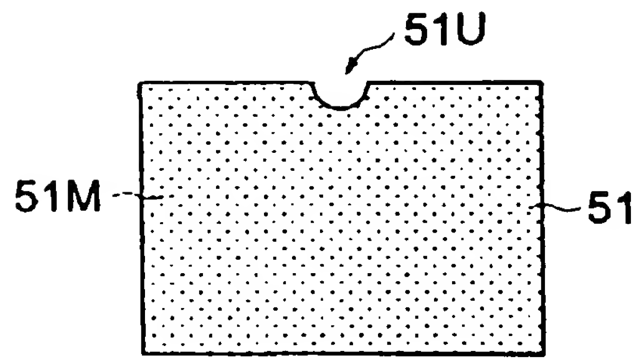


Fig. 11

(A)



(B)

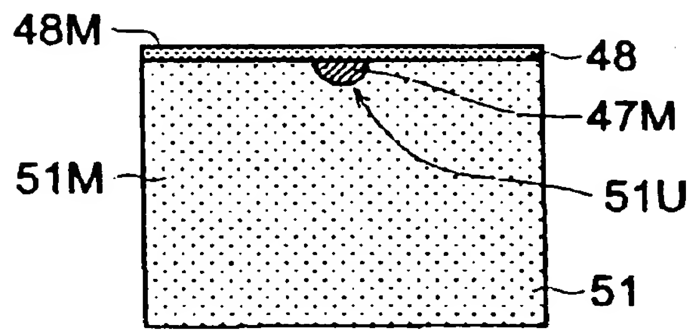


Fig. 12

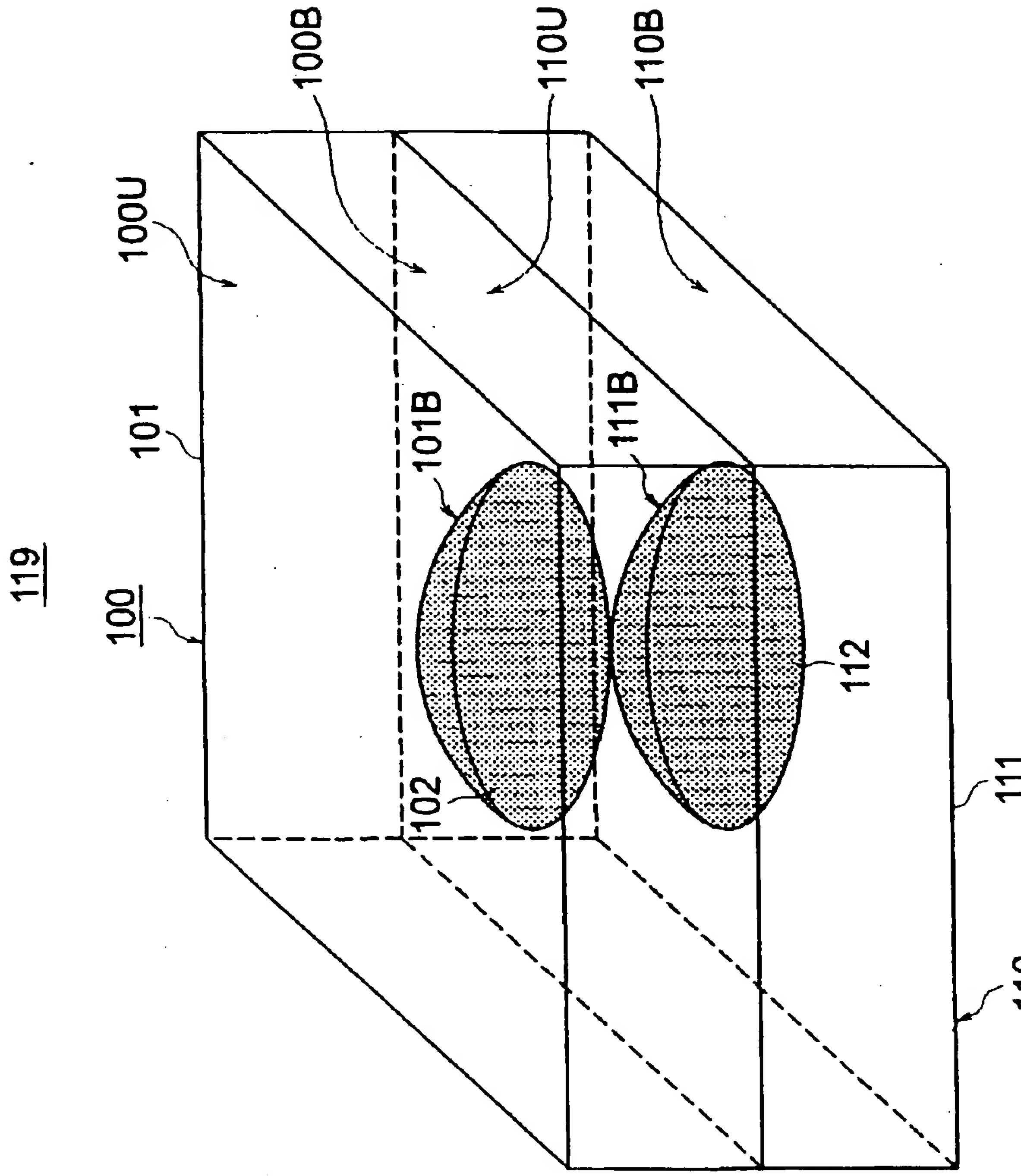


Fig. 13

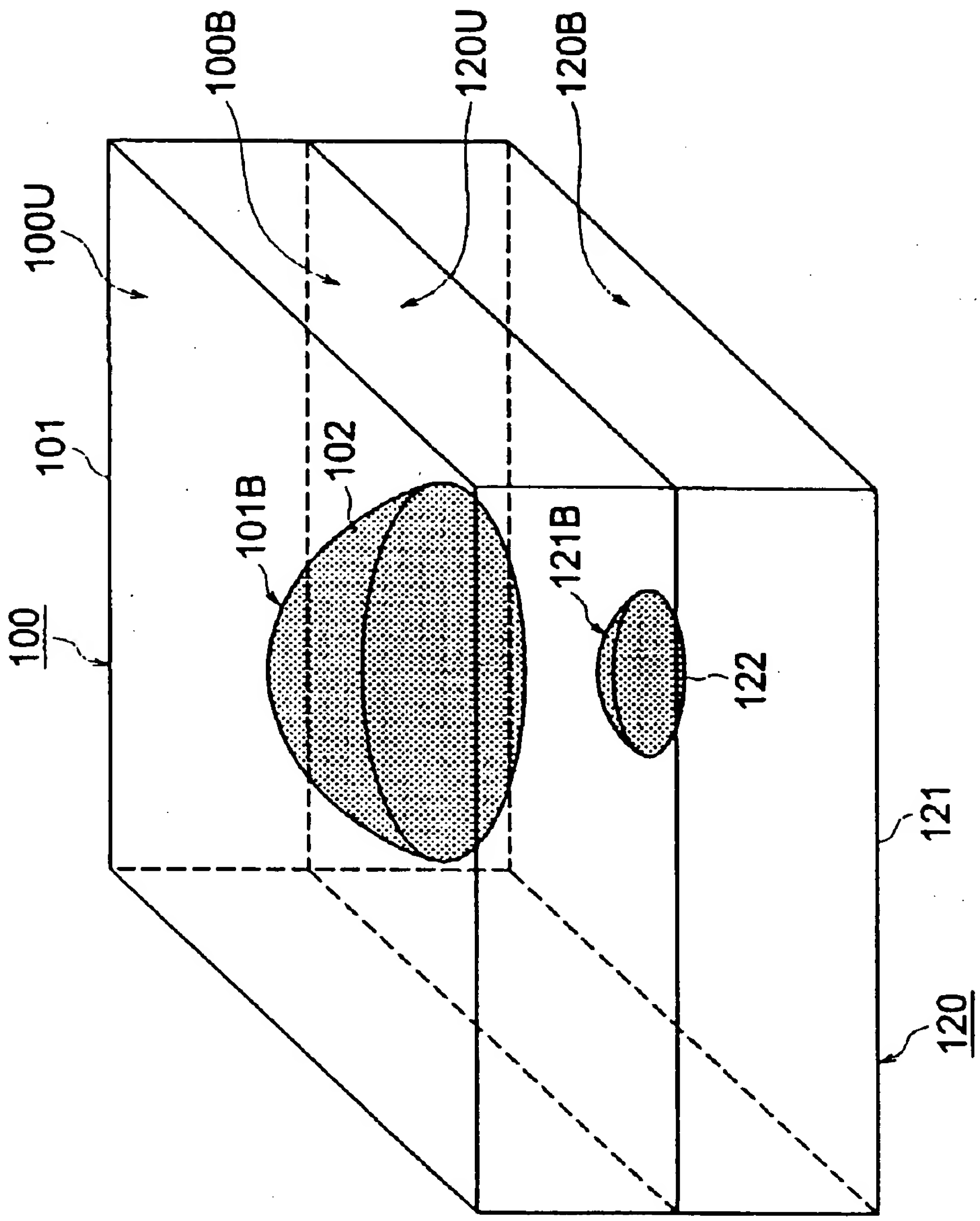


Fig. 14

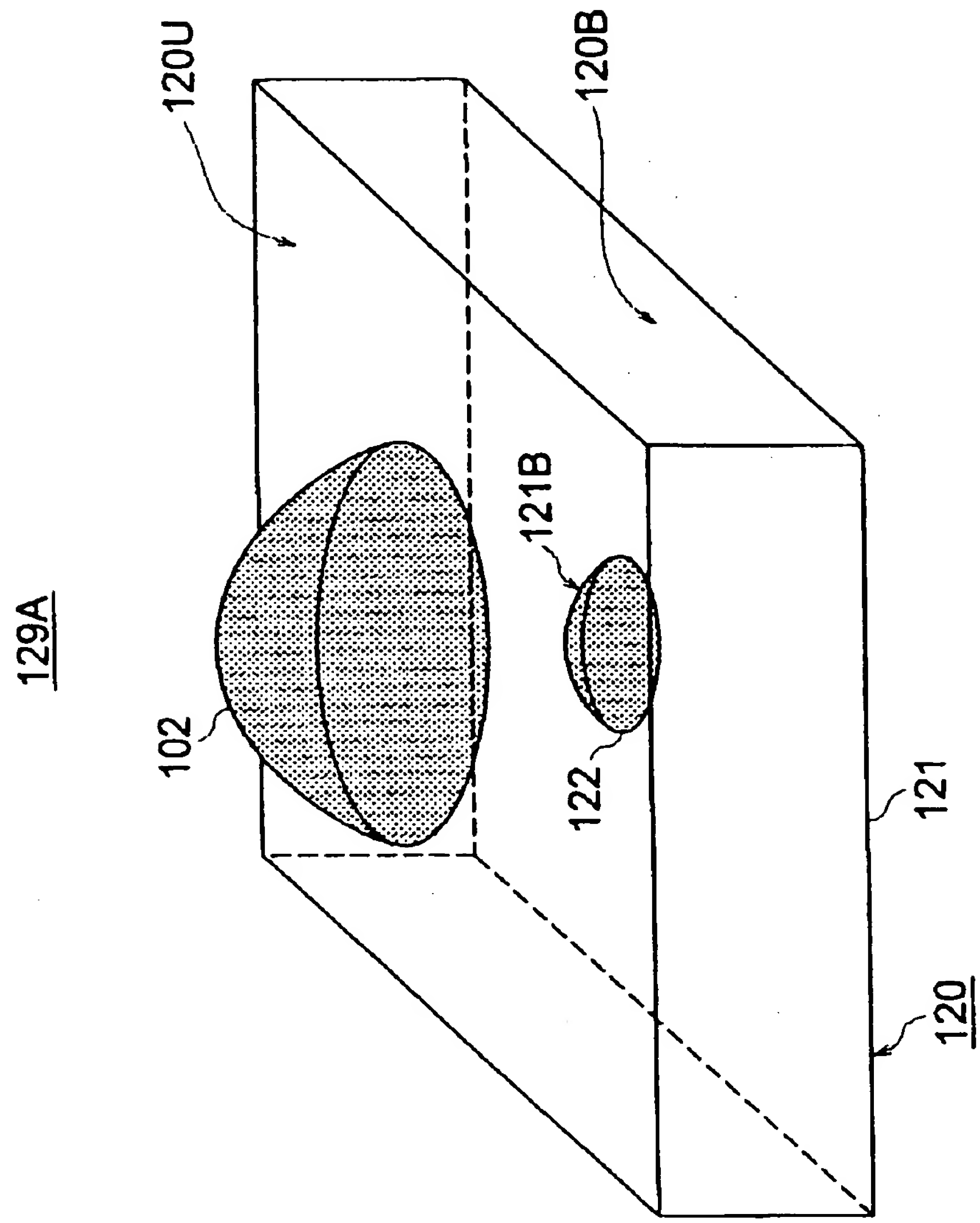


Fig. 15

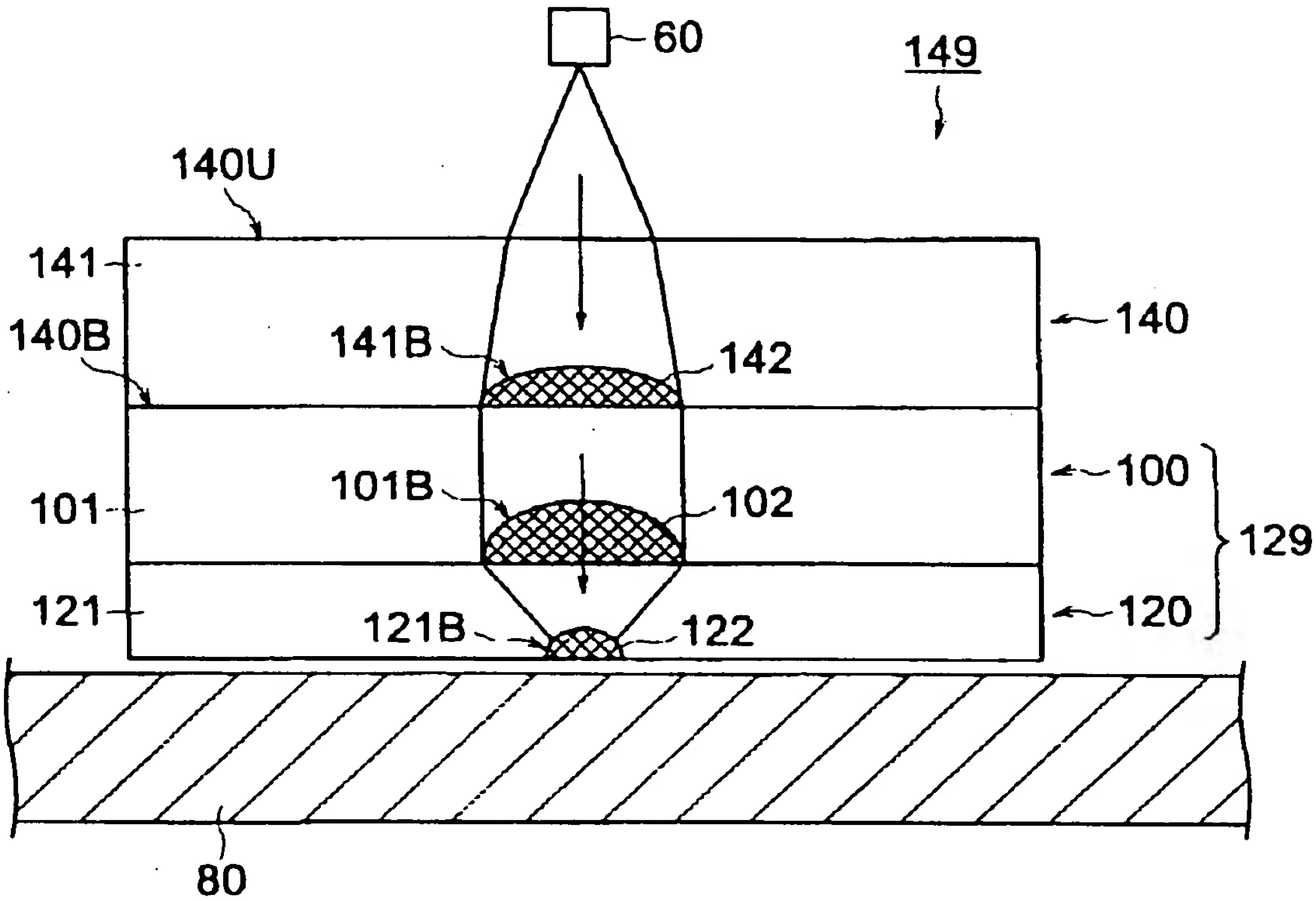

60
149
140U
141
140
140B
141B
142
101B
102
100
101
129
121
120
121B
122
80

Fig. 16

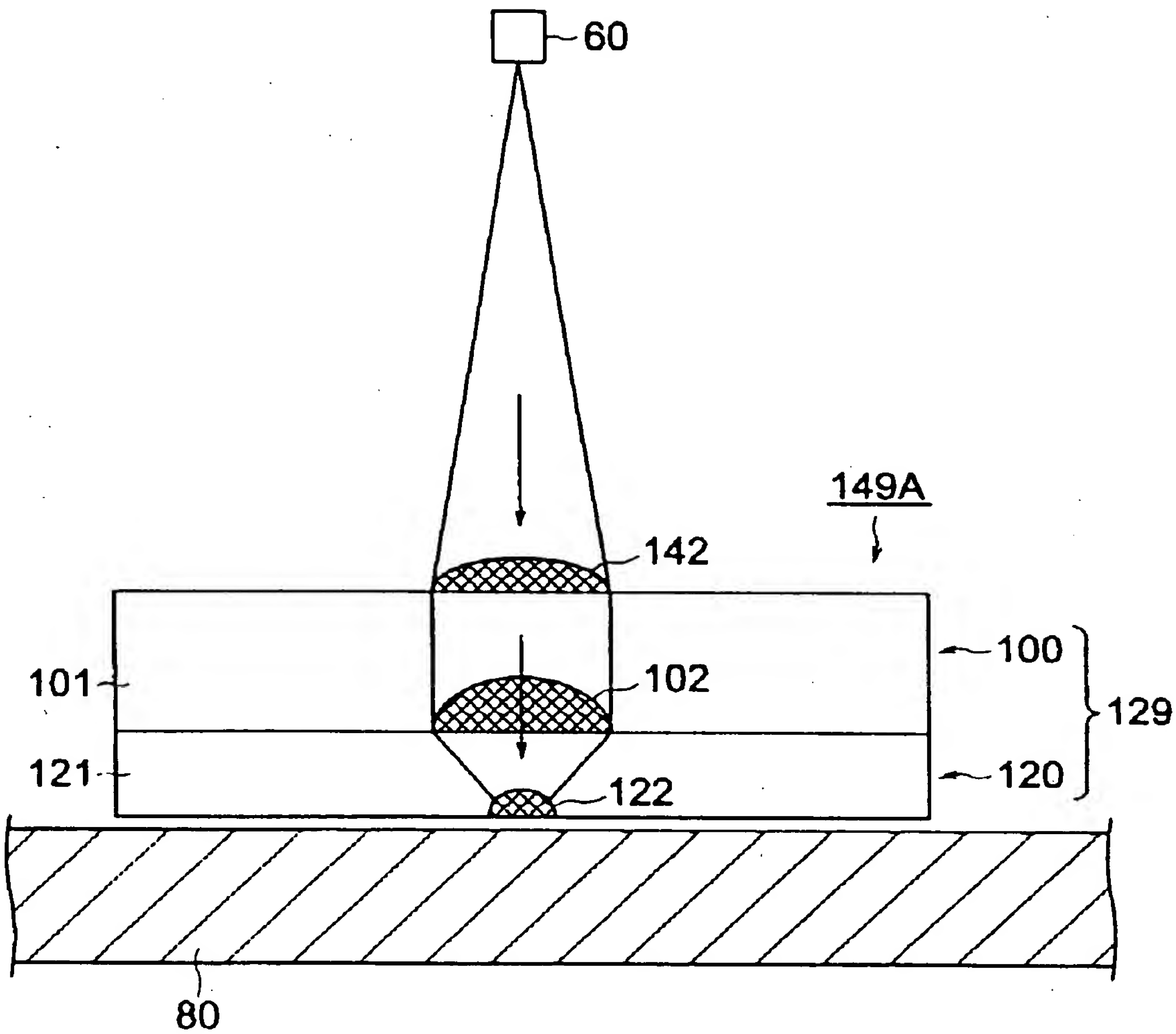
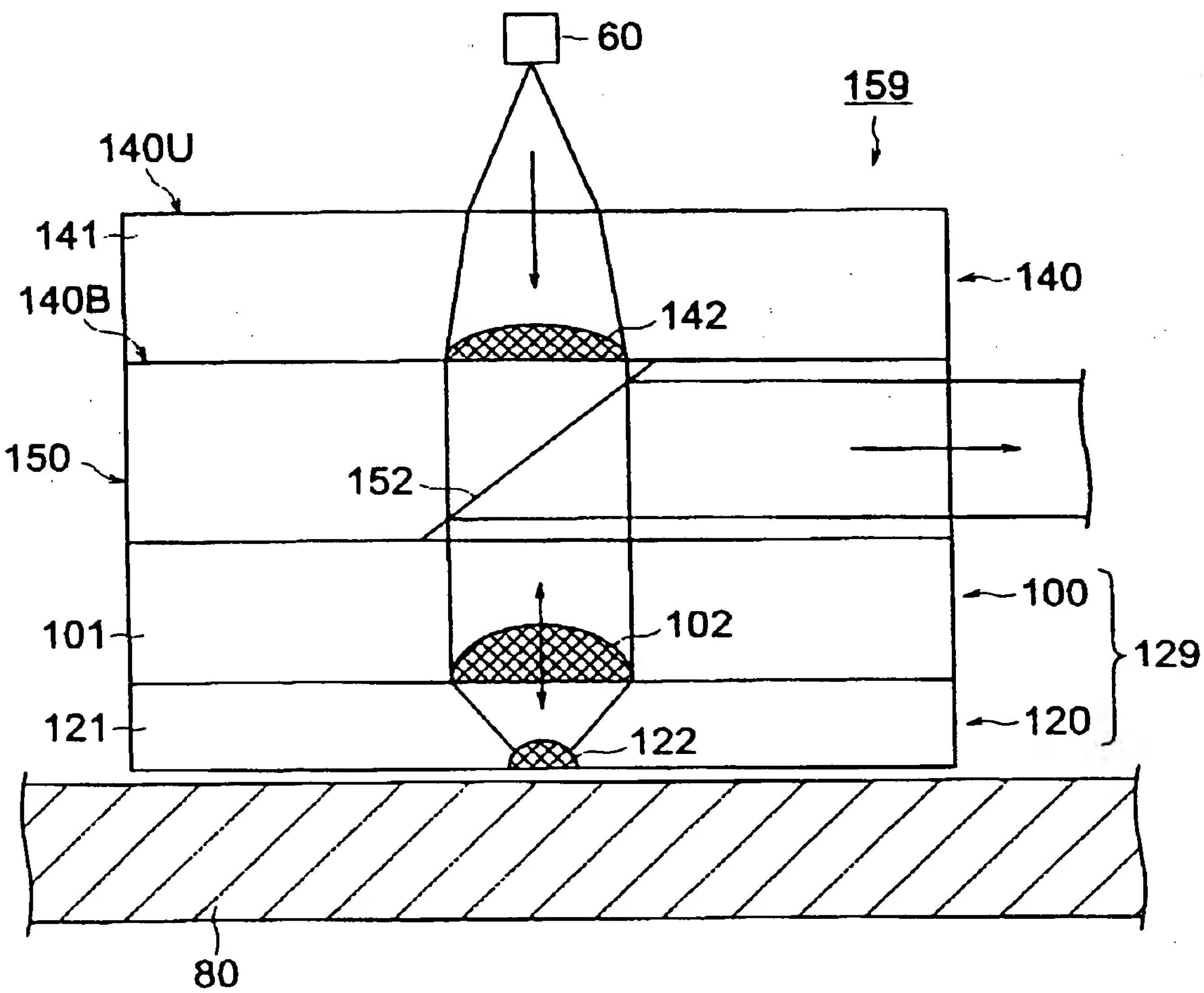


Fig. 17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152
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100
102
129
121
120
122
80

Fig. 18

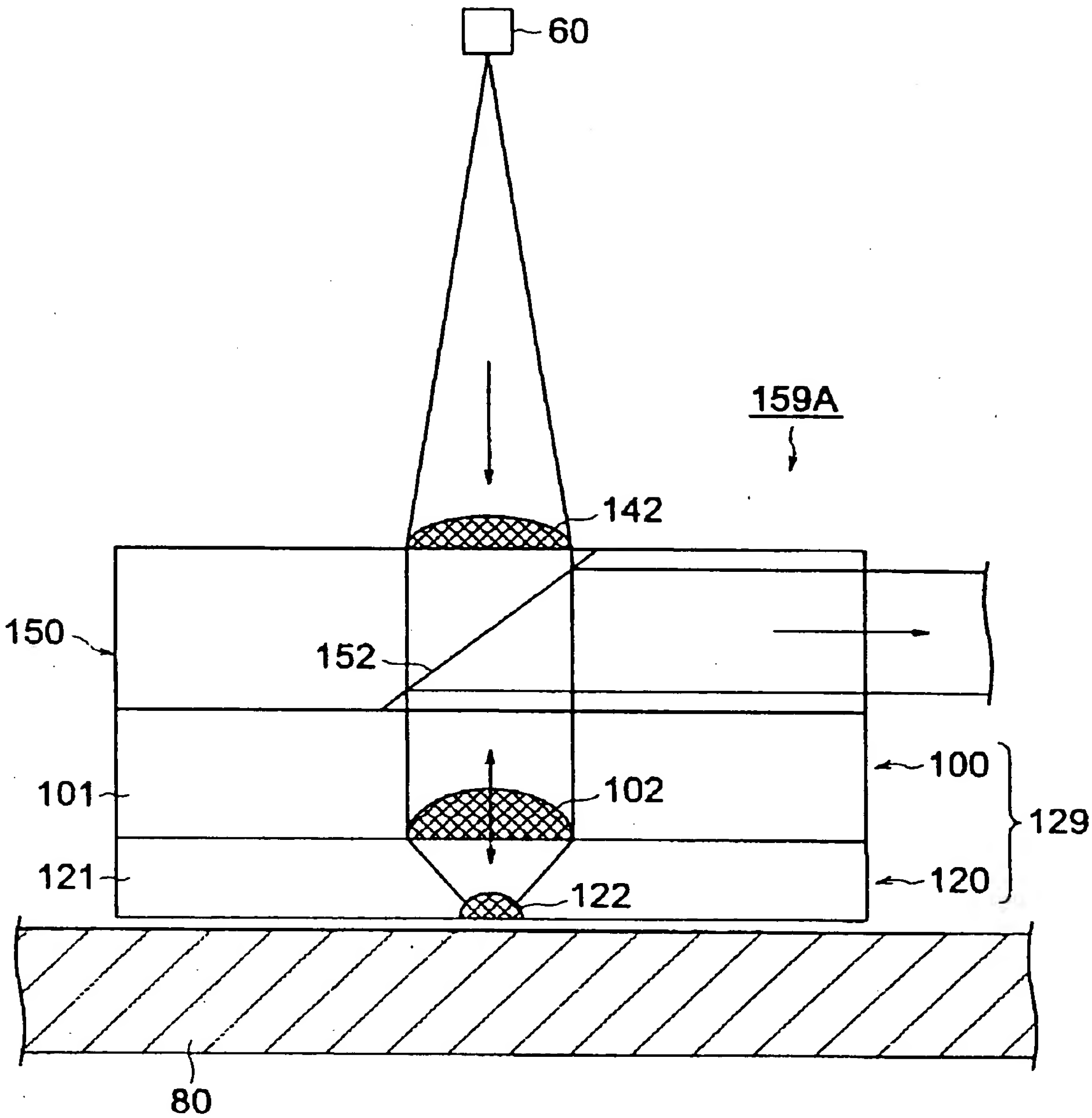


Fig. 19

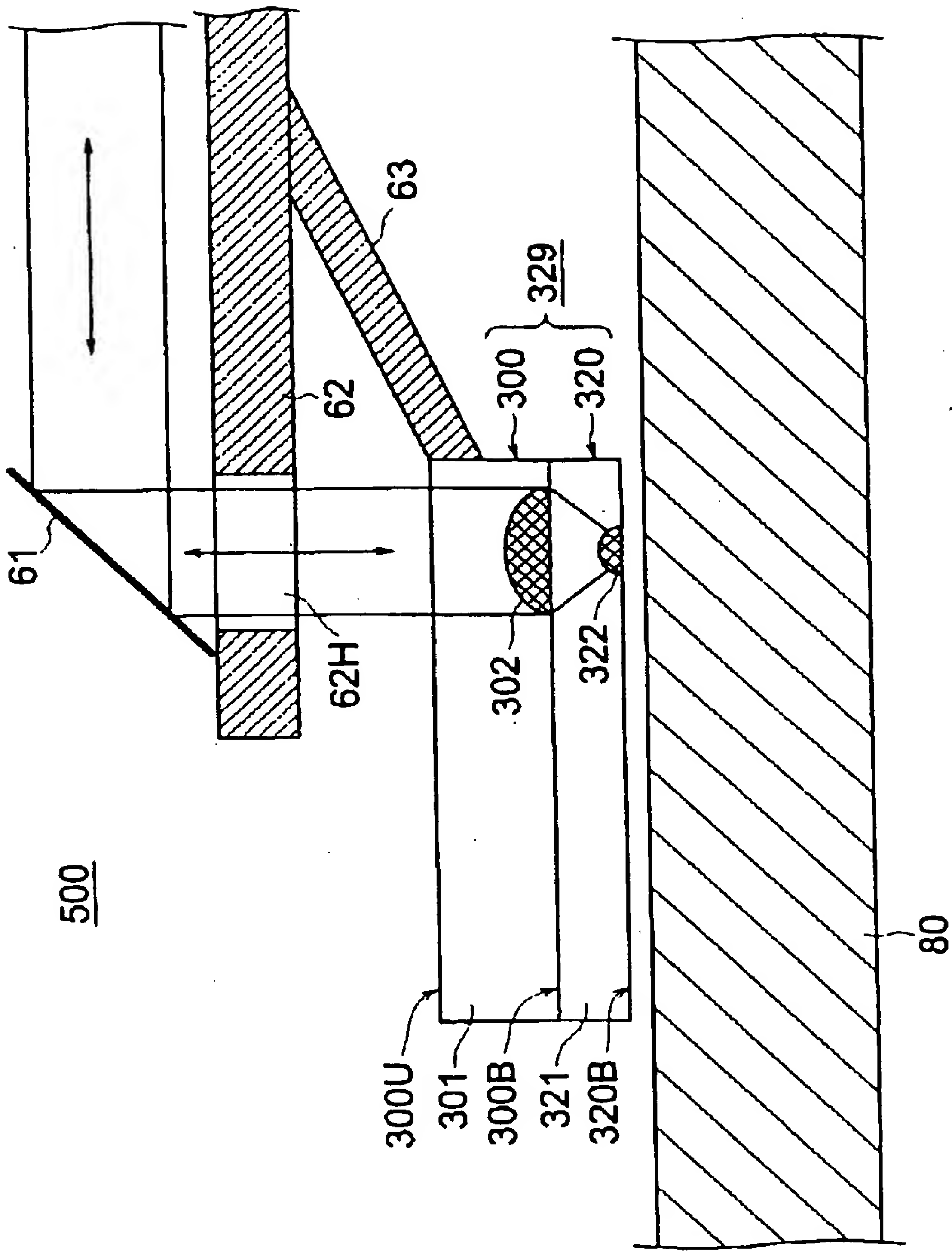


Fig. 20

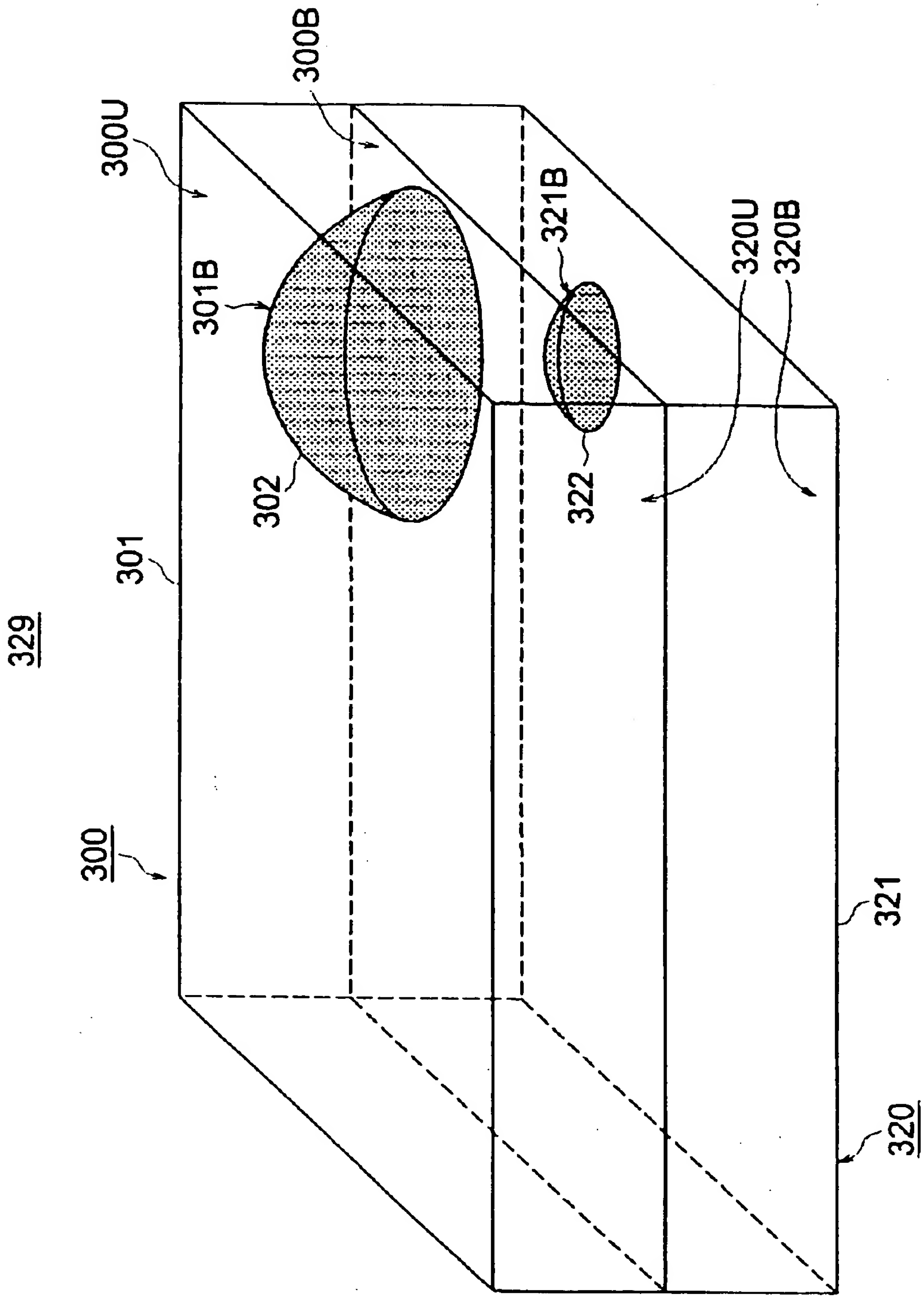


Fig. 21

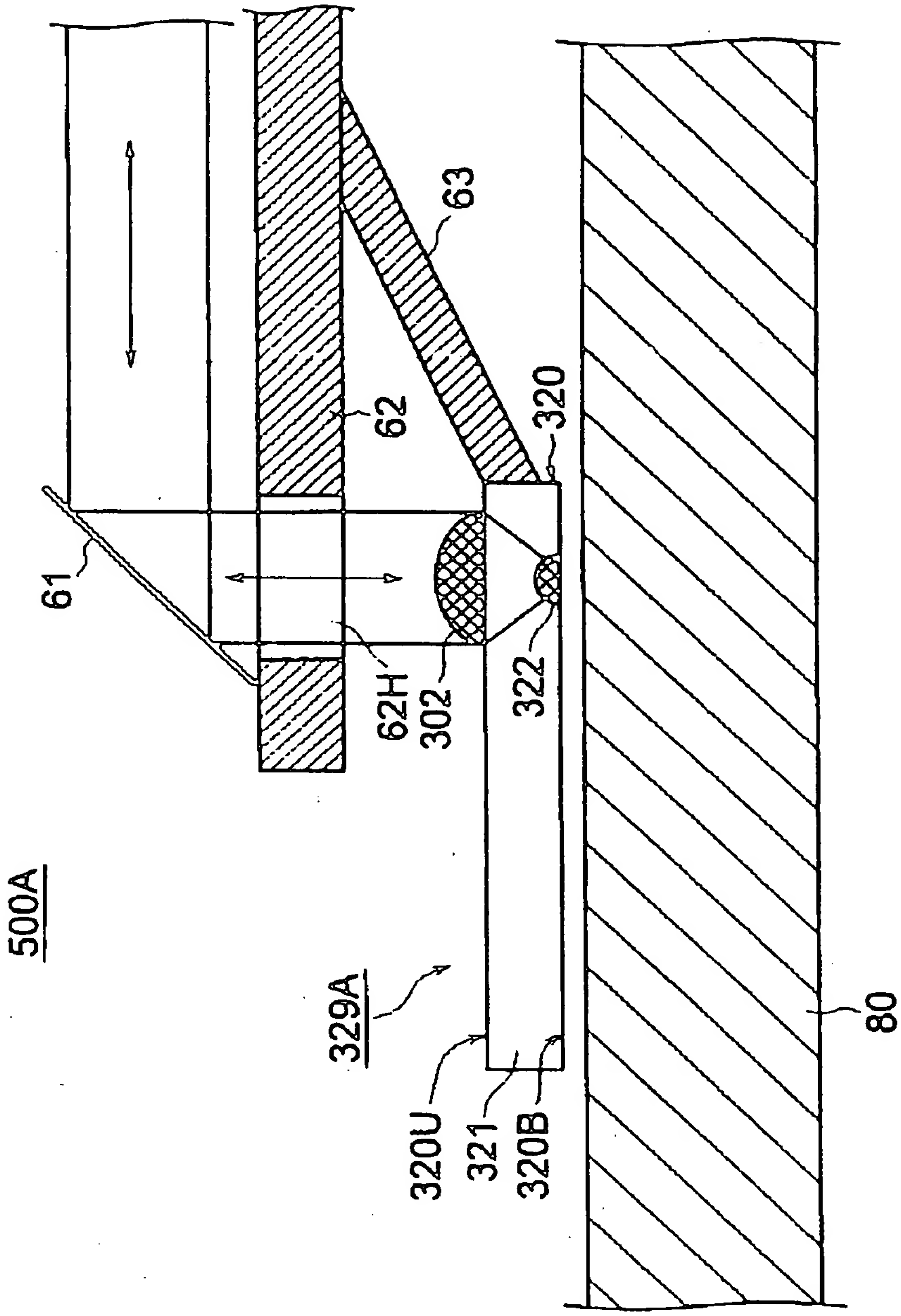


Fig. 21

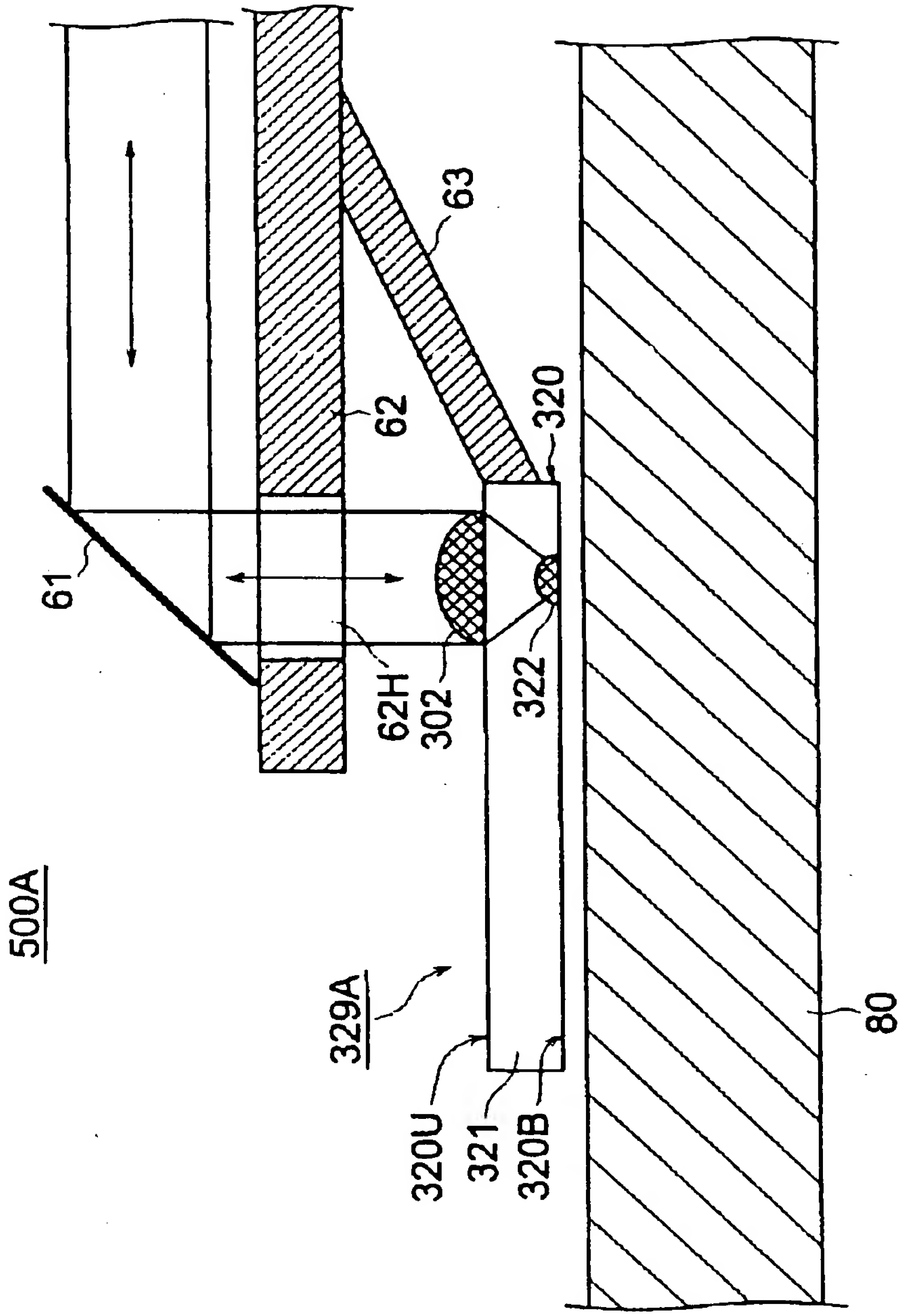


Fig. 22

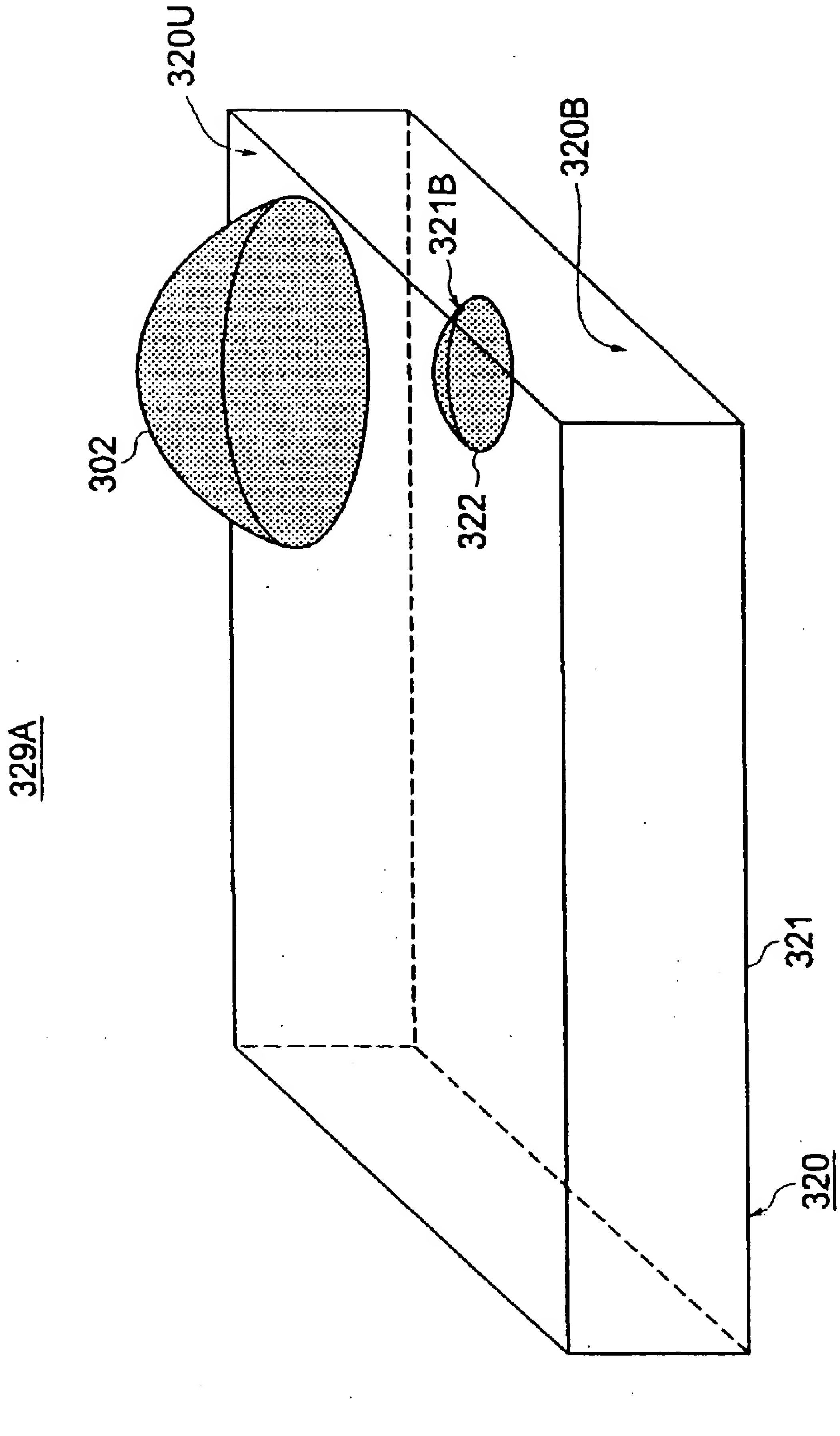
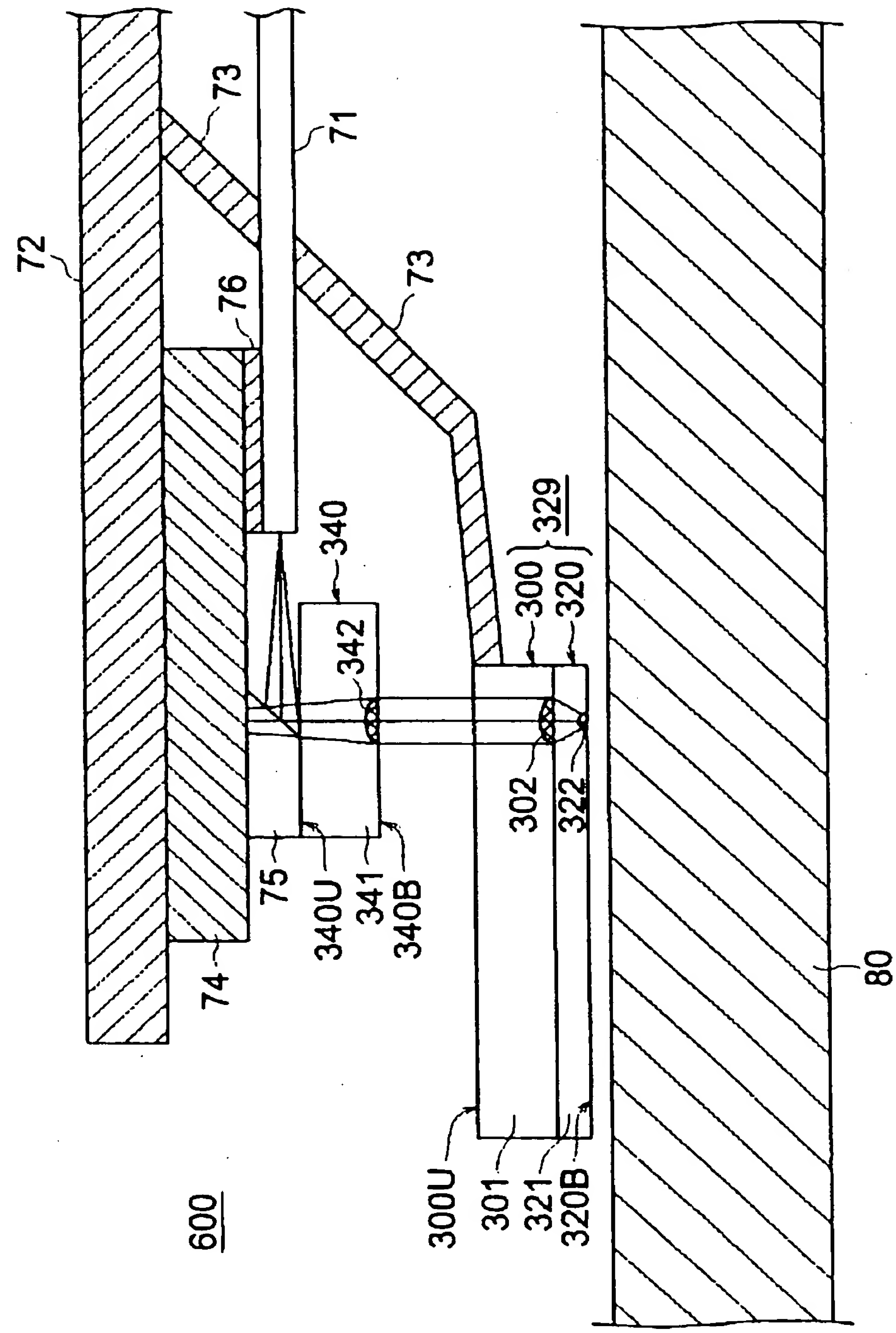


Fig. 23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340B
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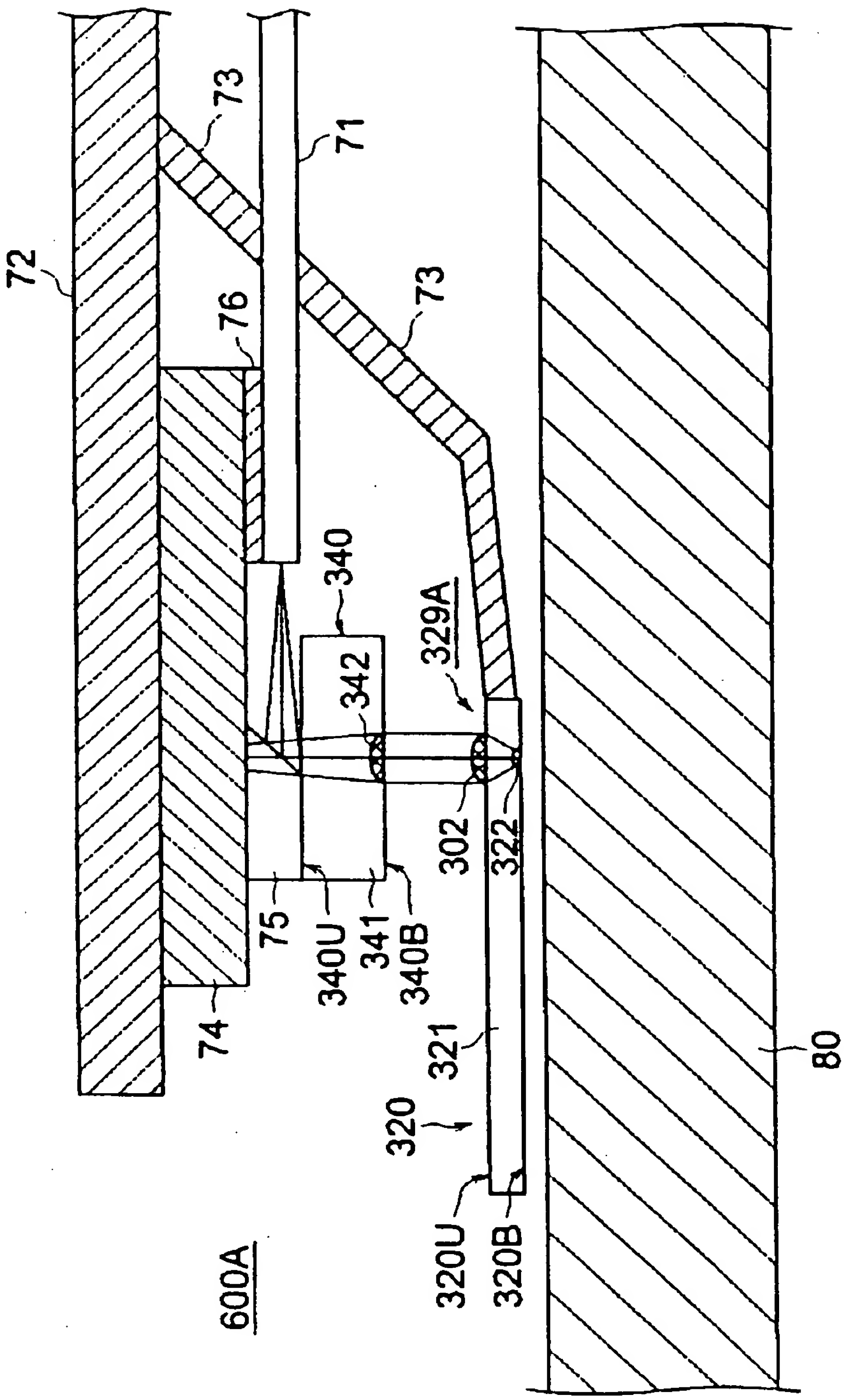
300U
301
321
320B

Fig. 24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600A
320U
320B

[NAME OF DOCUMENT] Abstract

[ABSTRACT]

[PROBLEM] To provide an optical device having a small size and a large numerical aperture.

[MEANS FOR SOLUTION] An optical device 100 has a base material 101 made of a first optical material and has a second optical material having a different refractive index from the first optical material. The base material 101 has a concavity 101B having a rotationally symmetric or approximately rotationally symmetric shape. In this concavity 101B is filled with the second optical material to comprise a lens 102. For example, the first optical material is made a quartz, and the second optical material is made silicon nitride (SiN) or gallium phosphate (GaP). By making the concavity 101B small, it is possible to reduce the size of the optical device 100.

[SELECTED DRAWING] Fig. 1